The
Papua and New Guinea
Agricultural Journal

Vol. 11 | March, 1959 | No. 4

Department of Agriculture, Stock and Fisheries,
Port Moresby

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Volume 4, Numbers 1, 2, 3 and 4.
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Volume 6, Numbers 1, 2 and 3.
Volume 7, Numbers 1, 2, 3 and 4.

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Volume 8, Numbers 1, 2, 3 and 4.

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Copies of all numbers of the *Gazette* to Volume 7, No. 4, are out of print.

Acknowledgments

The Director, Agriculture, Stock and Fisheries, and the authors of the papers in this issue relating to the work in New Ireland would like to express their appreciation to the plantation owners and managers for their co-operation and assistance.

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COCONUT EXPERIMENT WORK IN NEW IRELAND

By A. E. Charles.*

I. FIELD SURVEY AND INTRODUCTION.

A DESCRIPTION is given of a field survey of coconut plantations on the east coast of New Ireland, where extensive production decline has occurred in recent years. Palms were classified into four groups: healthy palms, old declining palms, heterogeneous palm stands, and stunted palms. These are related to soil types. Coral sands and red-brown clay-loams usually carry healthy palms, while yellow-brown clay-loams usually carry heterogeneous palms. It was concluded that the major factor causing decline probably was nutrient deficiency in the soil, therefore fertilizer trails should be laid down.

Introduction.

New Ireland is a long, narrow island lying between latitudes 2.5 and 5 degrees south. The south-eastern end of the island, which is wider and more mountainous than the remainder, is largely undeveloped, and the work to be described has been restricted to the north-western section. This consists of a strip of land about 150 miles long, and varying in width from 5 to 12 miles. The east coast, with a good motor road, is more fully developed than the west coast, and it is here that the survey was carried out.

There are about 50 coconut plantations along the east coast, with a total area of approximately 30,000 acres, all situated on the flat coastal strip. In addition, there are about a hundred native villages, all with groves of coconuts, which are used for food as well as for copra production. With the exception of four small villages in the hills, the whole native population in this section of the island lives right on the seafront.

About 80 per cent. of the plantations were planted wholly or very largely during the German administration of New Guinea, mainly between the years 1908 and 1918. Thus, the bulk of commercial plantings are now between 40 and 50 years old. However, the remaining 20 per cent. of plantations are mainly less than 30 years old. In the native groves there are palms of all ages, a few being probably as much as a hundred years old.

Nature of the Problem.

During and after the Japanese invasion of New Guinea, the coconut plantations were completely neglected for a period of from six to more than 10 years. Following their reopening, there was evident a most pronounced decline in productivity on many plantations. Accurate figures are unobtainable, but those given in Table I serve to illustrate the magnitude of the problem. It must be pointed out, however, that these figures are extremely approximate, and also that some of the pre-war figures may include a proportion of trade copra purchased from natives.

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TABLE I—*Copra Production in some New Ireland Plantations.*

Area in Acres	Pre-war Production (Tons/Annum)	Postwar Production (Tons/Annum)
400	130	100
400	140	50
890	280	120
1,300	300	220
375	215	100
750	230	200
975	350	120
350	85	50
675	240	160
550	275	200

Although this productivity decline has become more obvious since the war, it is not wholly a postwar development. Yellowing of fronds and decreasing productivity of palms had been noted on some plantations before 1940. The following comments, taken from inspectors' reports on what is a fairly typical example of the older plantations, are of interest. In 1940, there was noted the presence of " leaf droop, stunted yellow and tapered palms. Nuts small ". In 1948, the loss was recorded of 2,109 palms (out of an original 37,799) due to war damage. By 1951, a further 12,000 palms had " died of wilt and soil deficiency ".

On several plantations, too, there are very stunted palms which quite obviously have never made satisfactory growth. Dwyer (1939) reported what he described as a " maturation wilt " of coconuts just coming into bearing on a plantation near Namatanai. Thus, the problem is not only one of old palms declining, but also includes cases where palms have been poor through their whole life.

Evaluation of the factors involved in the general decline is complicated by war damage. Much direct damage was caused by bombing and strafing, particularly along the road, and one plantation near Kavieng lost at least half its palms from this cause, plus the cutting out of a large area for construction of an airstrip. Indirect damage is more difficult to assess. Overtopping of palms by secondary bush growth, and more especially their strangling by vines and creepers, may have led to the death of a number of palms, but it is doubtful whether many really healthy palms would be killed in this way. Bush growth certainly greatly reduced productivity of the palms, but within two or three years of clearing they appeared to recover completely. Indeed, it is not unlikely that a period of up to 10 years with nothing removed from the plantations may in some cases have had a beneficial effect.

Field Survey.

Between November, 1954, and June, 1955, a complete field survey of the problem was carried out. This included a soil survey, which has been described separately. The present report is concerned primarily with the condition of the coconut palms and an analysis of the probable cause of the declining productivity.

Clearing a New Ireland plantation of secondary bush growth resulting from wartime neglect.

A healthy New Ireland palm stand.

Palms encountered were classified into the four groups described below :

1. *Healthy Palms.*

Fortunately, almost all plantations have an appreciable proportion of normal, healthy palms. These are tall, with vigorous green fronds and carry, on the average, good crops of nuts. Except in the oldest plantations, these healthy palms may be expected to maintain their productivity for many years yet.

2. *Old Declining Palms.*

On a few plantations there are small areas of old palms which are quite tall and uniform, with fairly well developed green fronds, but a low average nut number. These would appear to be over-aged palms which have lived out their normal bearing life and are now in a declining phase. Such stands should be cut out and replanted, when a new stand of healthy young palms could be expected.

3. *Heterogeneous Palm Stands.*

Much more typical of the generally poor areas are very heterogeneous stands of palms. On young plantations, this is evident in very variable appearance of the palms. Some are well grown, with healthy, green foliage and good crops of nuts. At the other extreme are stunted palms, with yellow fronds, much reduced in number and size, and no nuts. All gradations between these extremes are found. In places, a single healthy palm may be surrounded by poor palms, and vice versa, but more usually patches of poor palms gradually grade into better palms, in an irregular pattern. Palm condition can sometimes be related to topography, there being a tendency for palms to be better in the depressions, but this is by no means universal.

In plantations more than 40 years old, the heterogeneity is not quite so marked, since many of the worst palms have died and most of those surviving are poor in appearance. However, there still remain patches where some of the palms are fairly healthy, contrasting with other patches where most palms have died. Heterogeneity is very evident in the height of palms, which may range from 25 feet up to more than 70 feet.

Stunted palms.

It is in this group that the worst production decline has occurred. On areas of this type, now about 25 years old, yield is estimated at 3 to 5 cwt./acre/annum, and it may be assumed that the older areas produced at least as well at the same age. These older areas now produce only 1 to 2 cwt./acre/annum, which is barely sufficient to cover maintenance costs. Furthermore, large areas, which had probably declined to a greater extent, have been completely abandoned.

About half the plantation palms would fall into this group, so that it constitutes the most urgent problem. It is most unlikely that replanting of such areas would be economic without some remedial treatment.

4. *Stunted Palms.*

Small localized areas of very stunted palms are found on many plantations. The worst of these, at 40 years old, have trunks only 15 feet tall, with yellow, stunted foliage and no fruit. Such palms are most commonly to be found where the area planted was originally grassland (*Themeda - Imperata* association) where constant burning of the grass has destroyed the fertility of the soil. There seems little possibility of any improvement of these palms.

Distribution of Palm Types.

A typical plantation has a strip of healthy palms along the sea frontage, about 200 yards deep. Beyond this depth palms are heterogeneous. Thus the proportion of good to poor palms on a plantation frequently depends on how far inland the plantation extends. The division between healthy and heterogeneous palms is sometimes quite sharp, but often there is a gradual merging of one type into another.

Such a description would fit an appreciable proportion of the plantations, but is not universal. There are a few plantations where palms on the seafront are poor, while further inland they improve. On one plantation there is a narrow strip of stunted palms, approximately parallel to the coast, with better palms on either side; another has a narrow strip of healthy palms along the shore, backed by a wide band of heterogeneous palms, but beyond this is a large block of quite healthy palms. There are also one or two plantations fairly uniform throughout.

The distribution was found to be related fairly closely to soil type, and may best be described under the major soil types encountered.

Leaning palms on coral sand, New Ireland.

1. *Coral Sands.*

These commonly support healthy and productive palms. However, there are many exceptions, including one plantation (the only one planted wholly on coral sand) which has been completely abandoned. It is likely that performance of palms on these soils depends largely on moving subsoil water, which may contain plant nutrients in solution. It is notable that some cases of poor palms are to be found where the ground is raised above the surrounding level. However, the soil type normally has a well-developed black, loamy surface horizon, 9 to 12 inches deep, overlying the sandy subsoil, and the palm roots undoubtedly draw heavily on this surface loam for both moisture and nutrients. Small areas are quite common on the coral sands where many palms are leaning, having been blown over at some period of their growth. These palms are usually only mediocre bearers and the condition is associated with poor development of the surface horizon.

The total area of coral sands on commercial plantations is not more than 2,000 to 3,000 acres, but the bulk of village groves also are on these sands. Hence, their place in coconut production in New Ireland is considerable.

2. *Clay Loams.*

The general pattern on these soils is that near the sea frontage they are shallow, red-brown in colour, and neutral to slightly acid in reaction. In most cases palms on such soils are healthy. Exceptions are on limited areas where it is probable that the topography allows excess drying of very shallow soils, and palms are heterogeneous or very stunted. In addition, on some of the oldest plantations many palms on this soil type are declining.

Further inland the soils are commonly deeper, lighter in colour (yellowish or red-yellow) and highly acid. Topography is usually uneven, with numerous depressions (sink-holes) where water disappears below the surface. There are occasional water courses, but they generally run no more than a few hundred yards before the water goes underground. Healthy palms are occasionally found on these soils, but more usually they are heterogeneous.

It is difficult to make an accurate assessment of the areas of these soil types, but there would be of the order of 14,000 acres each of the less acid and more acid clay loam soils. Of the latter, about half already has been abandoned.

Discussion.

In seeking a general cause of the decline, several possibilities were considered. Most of these were quickly eliminated, but, nevertheless, may be of some importance as contributing factors.

1. *Senility.*

The presence of both healthy and unhealthy palms of the same age on most plantations shows that senility is not the primary cause of decline. However, on many of the older plantations, replanting would be essential before any worthwhile improvement could be effected by any other means.

2. *Diseases and Pests.*

The distribution of unhealthy palms, often adjacent to fully-productive palms, excludes the possibility of these agents as primary causes. Nevertheless, insect pests may hasten the destruction of already debilitated palms, but there is no sign of any pathogenic condition of importance. Some plantations have been subject to occasional defoliation by coconut grasshopper, *Eumossula gracilis* Will. (formerly known at *Sexava*), which may shorten the life of the palms. It is surprising to note that, apart from one small area where several palms have been killed, damage by Asian rhinoceros beetle (*Oryctes rhinoceros*) and indigenous rhinoceros (*Dynastid*) beetles is negligible, despite the adundance of dead palms to provide breeding sites.

3. *Physiological Factors.*

(*a*) Water Relations.—Although rainfall in the area is 100 to 200 inches per annum, many planters said droughts are quite frequent and at times very severe. Several plantations have had grass fires through them in drought periods. However, although there may be small areas of shallow soil where drought is serious, drought is not likely to be a primary cause of the more widespread decline. The heavier clay soils would

contain large reserves of moisture in the subsoil even after the topsoil had dried out. These should prevent permanent damage to palms even after many months without rain, although temporary reduction in crop might result. In the lighter sandy soils, as has been suggested already, palms probably survive through drought because of a fairly shallow sub-surface water table.

Waterlogging also may be eliminated as a general factor, as the soils are mostly permeable (water is seldom seen lying on the surface even after heavy rains) and the underlying coral is porous, allowing rapid underground drainage.

(*b*) Soil Conditions.—

(i) *Texture.* Despite the high clay content shown by physical analysis, these coral-derived soils behave in the field as fairly friable loams. There are no marked differences in texture between soils from healthy and unhealthy areas of palms.

(ii) *Nutrient Status.* With the elimination of other possibilities, nutrient imbalance (deficiency or toxicity) remains as the most probable cause of decline. This is supported by the results of an analysis of a New Ireland soil reported by Dwyer (1939) which indicated a deficiency of potassium.

The range of conditions found in various palm stands could readily be explained on the basis of a deficiency. Stunted palms which have never grown well would indicate a soil initially very low in nutrient, while a gradual decline of originally fairly healthy palms would indicate a marginal content of nutrient in the soil, gradually becoming exhausted over the years.

The association on the clay soils between palm condition and soil type also supports the possibility of nutrient deficiency. The poorer palms are generally found on deeper and more acid soils, which, therefore, probably are older and more intensely leached.

Conclusions.

As a result of the survey, it was decided that field experiments with fertilizers and cultivation treatments should be laid down, supported by chemical analysis of soil and plant material. Because of the long delays if new plantings were to be used, tests should be made on existing plantations. The similarity of soil and palm conditions indicates that the problem is basically the same over the whole area, so that trials on any representative site should give results applicable to the whole.

Since it would be a matter of years before results of trials could be evaluated, it was considered that the original trials should be as comprehensive as possible, aiming to determine what elements were deficient rather than quantities of fertilizer required. Trials should be made on healthy stands, as well as on declining palms, to give a more comprehensive picture of soil conditions.

Concerning rejuvenation of the older stands, it was considered that replanting could not at present be recommended where the original stand shows severe decline. If premature senility is an indication of nutrient exhaustion in the soil, satisfactory growth could not be expected from replants. Most of the healthy stands should still have 20 years of productive life. However, planters would be well advised to commence replanting by stages so that new stands can be coming into bearing as the old ones cease to produce. Some planters have begun underplanting the old stands, a method of replacement which is being used in Ceylon. However, the practice in Ceylon is to thin the old palms to reduce competition with the replants, and it was considered desirable to carry out experiments to see what degree of thinning is necessary and to compare the economics with complete removal of the old stand.

(Part II of this article follows papers on the soil and chemical investigations.)

REFERENCE.

Dwyer, R. E. P. 1939. Some investigations on coconut diseases associated with soil conditions in New Guinea. *New Guinea Agric. Gaz.* 5 : No. 1. 37-53 ; No. 2, 2-47.

RECONNAISSANCE SOIL SURVEY—EAST COAST NEW IRELAND

By C. L. Van Wijk.*

This is a summarized account of a departmental Soil Survey report made by Mr. C. L. Van Wijk as an initial appreciation of the problem of declining plantations in New Ireland. The subsequent detailed investigations carried out, reports of which are published elsewhere in this issue, permitted the deletion of the general discussion from this report.—*Editor.*

Topography.

MOUNTAIN ranges occupy the northern and central parts of New Ireland. These reach their greatest height in the Lelet Plateau, a limestone massif of 3,000 feet to 4,000 feet. From this plateau, the ranges fall away to the south and north, although they are generally above 500 feet. The notable gap is at Namatanai, where the height is about 300 feet. The ranges end in the northern part of the island, and there are only isolated hills in the north-west of the island.

The parent material consists mainly of limestone and raised coral, so the landform is mainly determined by subterranean drainage. Although rainfall is considerable, there are no surface streams in some parts of the island.

Karst phenomena, such as a rugged surface, dolines, caves and big springs at the bases of cliffs are common.

The coastal belt consists mainly of undulating raised coral surfaces, broken by cliffs. In many places, this takes the form of terraces, usually dissected and irregular because of differential weathering.

The width of the coral fringe varies, but averages about a mile. However, the fringe is absent from the foot of the Lelet Plateau. Villages are sited mainly on flat coral-sand fringes along the foreshore. These fringes are mainly narrow belts, parallel with the shore, or isolated pockets, between the raised coral terraces and the coast. In other places, at the base of the terraces, sago swamps are found in seepages.

Alluvial deposits are mainly restricted to a few creek valleys in Central New Ireland and to the area between Namatanai and Samo.

Petrology.

Limestone and raised coral are the main parent materials from which New Ireland soils are derived. The limestone is found in association with fragments of old igneous rock, sandstones and shales, and quartzite, which apparently originates from upper tertiary rock formations.

A calcareous tuff formation, known as soapstone, is closely related to the limestone and coral. This material is of a greasy consistency and is believed to be the decomposed and structureless formation of old coral. In Northern New Ireland, calcareous tuff is found in isolated areas, mainly in steep ridges which dip away into the surrounding coral and limestone. Calcareous tuff is more extensive in Central New Ireland, from Lokon southward, where it is associated mainly with limestone and old volcanic materials. The area is badly eroded and unsuitable for agriculture.

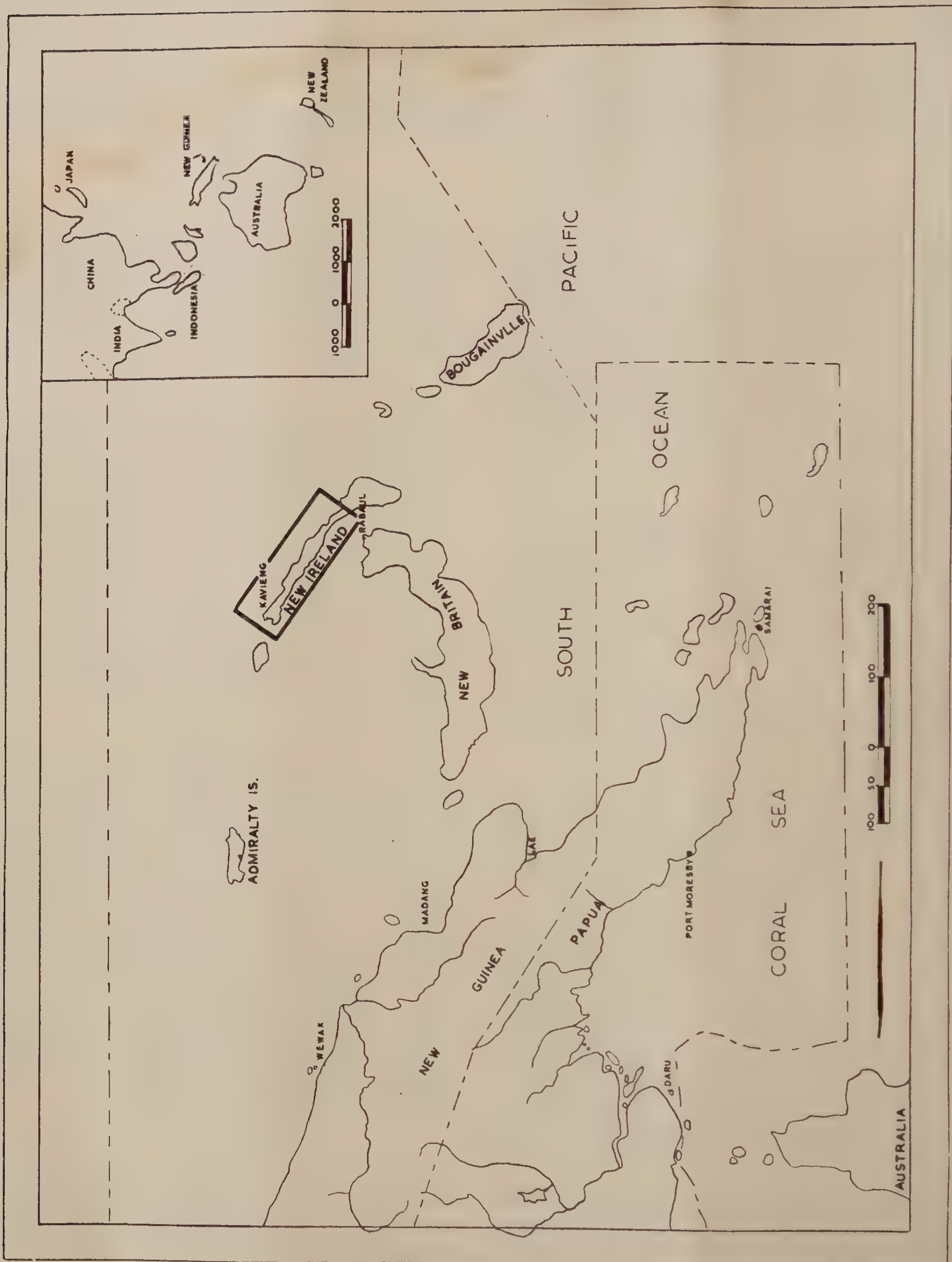
Evidence of old volcanic activity appears in Northern New Ireland, between the northern end of the limestone range and the flat or gently undulating northern section. Volcanics are found also in Central New Ireland as narrow strips fringed by soapstone ridges. Magnetite sand deposits indicate the likelihood of old volcanic activity in the centre of New Ireland. There are also volcanic products on the west coast.

Volcanic areas are generally of easier relief than the limestone country, but they are generally inaccessible, except possibly in parts of Northern New Ireland.

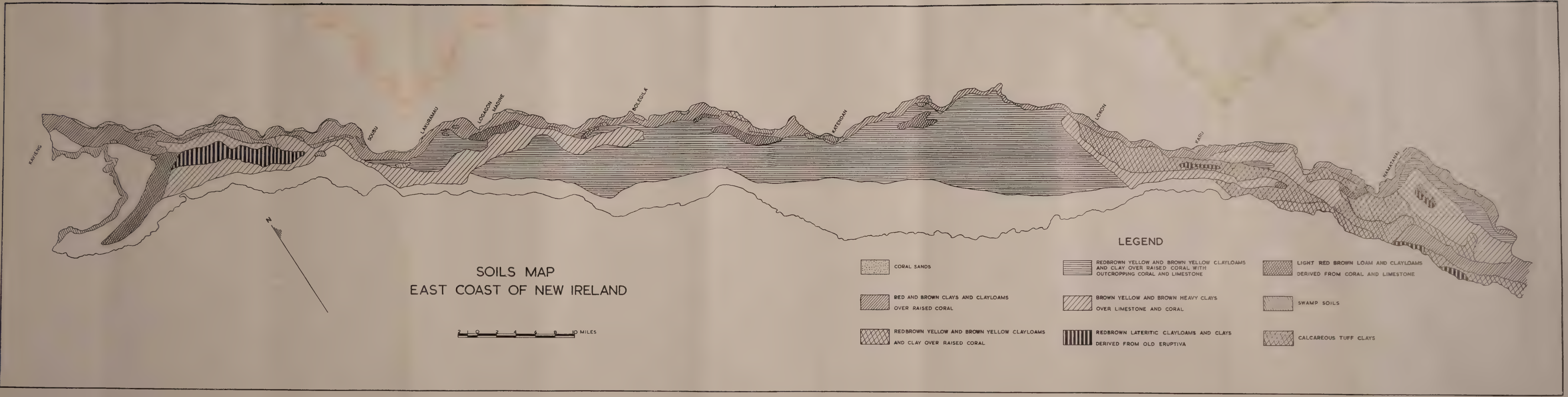
Rainfall.

Reliable rainfall totals for many areas have not yet been accumulated. However, the main rainy season is from November to April, during the north-west monsoon. But

* Formerly Soil Survey Officer, Department of Agriculture, Stock and Fisheries.



Location map of area surveyed.



KAVIENG
SOUBU
LAKURAMAU
LOGAGON
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SOILS MAP
EAST COAST OF NEW IRELAND
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LEGEND
CORAL SANDS
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LIGHT RED BROWN LOAM AND CLAYLOAMS DERIVED FROM CORAL AND LIMESTONE
SWAMP SOILS
CALCAREOUS TUFF CLAYS

there are also showers from May to September, the period of south-east winds, along the east coast. These falls are local in character, scattered and not very heavy. It is probable that the Lelet Plateau has a higher rainfall, while falls are considerably lower in the Karu-Namatanai part of Central New Ireland, where droughts occur.

	J.	F.	M.	A.	M.	J.	Jy.	A.	S.	O.	N.	D.
Kavieng .... (10 years)	12.20	11.60	11.35	12.06	9.93	9.55	10.36	10.67	8.03	8.12	9.24	10.72
					Total 123.23 inches.							
Logagon	13.96	15.85	12.35	11.13	9.54	6.51	7.03	10.08	5.50	8.55	8.89	12.86
					Total 122.25 inches.							
Namatanai ..	19.68	16.87	16.61	14.72	8.80	7.04	8.55	7.39	5.93	8.99	11.39	16.87
					Total 142.84 inches.							

The only rainfall figures available are from Kavieng and Logagon in Northern New Ireland, and from Namatanai in the central part.

The rainfall and its monthly distribution favours healthy palm growth on mineral soils, but on coral and limestone soils, which are mainly shallow and well-drained, the effect of a dry period is marked. More permanent water is found in hill depressions, but, where drainage is impeded by impervious clays, swamps result.

Vegetation.

Rain forest covers the mountain ranges, but this generally appears to be poor in composition and species. On the raised coral belt, where rainfall is lower, the forest cover is even poorer and, by comparison, appears stunted. It is usually replaced by a secondary forest composed of only a few species, but with a dense undergrowth of vines, ginger and wild hemp. Forest vegetation on the calcareous tuffs is often scanty, with big windfall gaps, caused by sodden conditions in the wet season.

On the raised coral terraces, grassland patches are common. A characteristic species of Pandanus has given the country a savannah-like appearance. These grasslands are probably artificial, having been formed by the few hardy species which survive the annual burns.

Swamps appear mainly where there is seepage, as on the boundary of coral sands and reefs in Northern New Ireland. From Katendan northward, mangroves and sago swamps are fairly extensive in the form of a belt half a mile or less in from the shore.

Nearly all the agricultural land is within two miles of the coast. The natives use the traditional form of bush-fallow agriculture with a rotation of a crop in one year, followed by a re-growth of five years. About 50 European and Chinese-owned plantations of coconuts alternate with many village plantings of the palm.

Soils—General.

Except for small areas of volcanic and old tertiary formations, most of Central and Northern New Ireland is composed of limestone, coral and calcareous tuffs. On this parent material, soil is formed from the inorganic constituents originating from the upper tertiary sediments and old volcanic deposits.

Generally speaking, the fertility of a soil will be higher and vegetation will be more abundant when more mineral matter is available. Excess of calcium carbonate helps in two ways. Firstly it saturates the colloidal clays with lime, and secondly it keeps the soil flocculated into a coarse dispersoid phase, when it is penetrated by water and air. This permeability causes drought in dry seasons, particularly where soils are shallow. The limestone and coral in itself is very permeable and groundwater is always at a considerable depth. Under these aerobic conditions, the iron compounds show predominantly brown-red to red colours.

However, under humid conditions, in the presence of organic matter, calcium carbonate is dissolved and leached downwards, thus lowering the pH in the topsoil, resulting in the formation of iron concretions and a bleached brown-yellow colour. The clay has a heavier texture and becomes stickier and more plastic as the fine, dispersed iron compounds transform into a course disperse condition.

Calcareous tuffs are impervious. Consequently this parent material is water-saturated during wet periods. Under these conditions hydrogen clay, which disintegrates

easily, is formed. This clay is liable to heavy erosion and creep. During the wet season, the calcium carbonate is gradually leached out, especially if organic matter is available. The soil pH does not fall below neutral and leaching is less extensive than in permeable limestone and coral. During the dry period the pH increases slightly. This soil dries more slowly than the red and brown-yellow clays.

G. W. Robinson* describes their characteristics as follows. " Soils derived from limestone belong to the group of terra rossa. They have a low base status, sometimes even in the presence of fragmentary limestone, and a type of organic matter of a light colour. Colour of the mineral soil is red or reddish-brown, associated with a type of clay having a S_1O_2/R_2O_3 ratio of two or less, in which there is a certain proportion of free sesquioxides." Other writers suggest that the reason for the change in colour from red to brown-yellow in the coral and limestone soils is caused by a difference in saturation of the clay complex.

Although the red clay is slightly acid, it seems that the clay complex shows a certain saturation with bases mainly calcium. The red clay is mostly friable and well aerated. The brown-yellow coral clays represent the less-saturated type in which calcium and bases in the clay complex have been replaced by hydrogen. These soils are heavy, plastic and impermeable. Water movement is disturbed and once the soil is saturated, anaerobic conditions and reduction processes prevail.

Volcanic soils derive mainly from old andesites and show the characteristic of lateritic weathering. They gradually increase in heaviness with depth, from loam to clay to medium clay, with a reddish-yellow mottled layer. These soils are permeable and have a favourable water-holding capacity. Unfortunately they are mainly in steep positions and are heavily eroded.

Profile Description.

1. *Coral-sand* consists of yellowish-white coarse coral fragments with no profile differentiation. The soils are porous and cannot hold water, except in the dark humic top layer. However, these flat sands have a favourable groundwater table, and tidal influences cause movements of subsoil water, which assists coconut growth. Under equatorial rainfalls, these coral-sands grow good palms, which are healthy in appearance as long as competition by shrubs and rival plants is eliminated. At present, these coral-sands represent the best palm soils on the east coast of New Ireland.

2. *Red-brown to red clay-loams/light clays over raised coral.*

Description of an average profile :—

- 0-1 in.—Dark-brown humic, permeable, friable and crumbling loam with numerous roots, merging into—
- 1-6 in.—reddish-brown, permeable, friable, crumbling to slightly sticky clay loam, gradually merging into—
- 12-20 in.—red-brown clay, cloddy to granular, permeable and less friable, due to increased stickiness and plasticity. Root development is favourable. Merges into—
- 20-36 in.—red-brown clay, friable and permeable, cloddy to granular light clay, less sticky and plastic, containing soft earthy-blue iron concretions. Roots are developed through this layer.

Variation in profile composition is caused mainly by relief. Shallow red to red-brown clay-loams are restricted to the ridges which are liable to severe erosion. Deep profiles are accumulated from the ridges. Depressions with poor drainage are often swampy during the wet monsoon. Consequently a subhydric decrease in pH takes place, accompanied by movements of soluble iron compounds and the formation of iron concretions. The sticky and plastic heavy subsoil in these localities shows a brown-yellow mottling with red streaks.

The above red clay-loams and clays are restricted to the raised coral and cliff country for a distance of half a mile to three-quarters of a mile from the coast. The topography shows no marked difference from the remaining raised coral areas further inland, which are occupied by the brown-yellow clays.

3. *Brown-yellow clays.* The average profile of this soil type has the following characteristics :—

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* *Soils, their origin, constitution and classification*—1932.

0-10 in.—a brown-yellow permeable, friable, crumbling to granular slightly humic clay-loam. Slightly sticky and plastic in consistency, gradually merging into—

10-12 in.—yellow-brown, less friable and less permeable, cloddy clay with increased stickiness and plasticity, merging into—

12-36 in.—yellow-brown, cloddy, compacted, heavy impermeable clay, usually with bluish iron concretions.

This soil type tends to bogginess during the rainy season, although the soil takes a long time to become saturated. In this type, palms are alternately exposed to droughts during dry periods and to waterlogging in wet season. These heavy clays are found inland on the hilly, raised coral and extend to the lower mountain ranges.

3. (*a*) *Red-brown-yellow clay-loam to clay.* An intermediate type is the red-brown-yellow clay-loam to clay over raised coral. In physical properties this type is closely related to the red clays. However, the predominantly yellow to yellow-brown colour and the presence of blue-iron concretions indicate a chemical difference. Profile characteristics of this type are—

0-3 in.—A grey-brown, mellow permeable, humic crumbling loam, feeding roots plentiful, merging into—

3-8 in.—brown-yellow, permeable, friable, less humic loam, gradually merging into—

8-12 in.—reddish-brown-yellow, permeable, friable clay-loam, poor in humus and slightly sticky and plastic, gradually merging into—

12-36 in.—reddish-yellow, permeable, friable light clay, increasing in stickiness and plasticity and containing soft blue iron concretions. Root development in this latter is satisfactory.

Although physical properties of this type are more favourable than the brown-yellow clays, coconut palms are less healthy and productive than on the red clay/clay-loams along the foreshore. The economic life is definitely shorter. Reasons for the early decline could be the occurrence of droughts and deficiences in plant nutrients.

Grasslands developed on this soil type usually show a deteriorated topsoil, which is dark, due to the presence of fine charcoal. Water percolation is disturbed and anaerobic conditions prevail in the upper layers.

4. *Red-brown loams to clay-loams.* Soils of the best physical properties are found in small bands at the base of limestone ranges near Logagon and Magina. The soil profile generally has the following characteristics :—

0-12 in.—Red-brown loam, crumbling, friable and permeable, merging into—

12-30 in.—reddish-brown clay-loam, crumbling and permeable. Roots all through the layer.

30-34 in.—red-brown-yellow light clay, crumbling, friable, permeable, and containing a few concretions.

34-36 in.—red-brown-yellow, red-streaked clay-loam, crumbling, friable and permeable.

These light-structured loams are found also in depressions and valleys in the limestone ranges, where eroded material accumulates. These soils have a good waterholding capacity, and for this reason are preferable for native gardens. However, the areas are scattered and small. This soil is quite suitable for cocoa, as at Soubu plantation and Bolegila, five miles inland.

5. *Calcareous tuff soils.* This tuff is associated with limestone and volcanic material. Soils developed in situ are heavy, puggy, impermeable yellow-brown clays. The soil profile shows the following characteristics :—

0-4 in.—Grey-brown clay-loam, friable, crumbling and humic, suddenly changing into—

4-10 in.—impermeable, cloddy, compacted brown clay containing tuff fragments. Consistency is more or less greasy.

10-36 in.—mainly decomposing tuff fragments and impermeable, compact brown clay. Very greasy.

These shallow profiles get waterlogged after only a short period of rain. The saturated soil disintegrates and the vegetation topples. Even on deeper profiles, a common symptom is fallen trees and palms. Deep, well-drained profiles on hill sites seldom reach the stage of saturation and accordingly

support an abundant natural vegetation. Coconut palms on these soils are healthy, green and productive.

The impermeability of the parent material causes temporary waterlogging of subsoils, which is shown by a grey-brown and reddish mottling. Calcareous tuff areas have mainly a surface run-off and unlike the limestone country, small creeks are found.

6. *Volcanic soils.* There are small areas of soil over old volcanic material in Northern and Central New Ireland. Although the soil is preferable for agriculture, the areas are inaccessible and also are generally of dissected relief, which restricts their value. Profile characteristics are :—

0-8 in.—Grey-brown loam, crumbling to granular, friable, permeable and of a good water-holding capacity. This layer is reasonably well provided with humus. It merges at—

8-18 in.—into yellow-brown clay, crumbling to granular, permeable and friable. Humus content is very low, but roots develop through the area. It merges gradually at—

18-30 in.—into yellow-brown clay, granular to cloddy, less friable but permeable. Roots are less numerous. Merges into—

30-36 in.—yellow-brown medium clay, cloddy, less permeable and less friable.

The third layer usually shows a red, grey, blue and yellow mottling associated with the lateritic weathering. Soils are mainly eroded and shallow on steep slopes, where old volcanic parent material (andesite) often appears on the surface.

7. *Alluvial soils.* These are found in narrow strips along some creeks. These alluvia are mainly brown sand, to sandy loams of good permeability. At depth they are gravellish, but the soil is at least five to six feet deep. The ground water table is at a favourable depth and water movement is unimpeded. These alluvia are quite suitable for growing coconut palms, rice and cocoa, but the area is restricted and already occupied.

EVIDENCE OF POTASSIUM DEFICIENCY IN COCONUT PALMS ON CORAL-DERIVED SOILS IN NEW IRELAND FROM ANALYSIS OF NUT WATERS, HUSKS, FRONDS AND SOILS.

By S. C. Baseden * and P. J. Southern.†

THE analysis of soil and plant materials from areas where coconut palms are in various stages of decline, shows that the potassium status of the palms and soil is closely related to the degree of decline and the severity of the deficiency symptoms.

There is evidence that the potassium reserves of large areas of the coral-derived soils in New Ireland are inadequate for the satisfactory growth of coconut palms.

Introduction.

The area investigated involves nearly 150 miles of the coastal fringe of the east coast of New Ireland, extending from Kavieng to south of Namatanai. It embraces about 50 plantations with a total area of some 30,000 acres, or approximately 1.5 million palms. It is estimated that one-third to one-half of this area carries palms which are chlorotic, bearing few nuts, and in the more extreme cases are dying prematurely.

In general, there is a very marked decrease in the productiveness of the palms with increasing distance from the shore, which coincides with a change in soil characteristics.

The decline of coconut palms in New Ireland has been evident for some time, and was the subject of a report by Dwyer (1940).

A soil survey carried out in 1955 (Van Wijk) outlined the main soil types, and, subsequently, samples for analysis were collected by the writers from 15 plantations, which were considered representative of the main problem.

The diagnostic work was based mainly on a comparison of the analysis of soil and plant materials taken in September, 1957, from sites where palms were healthy and in various stages of decline. The age of palms in the areas investigated was estimated at 30-45 years.

Description of the Soils.

The main soil types of the east coast of New Ireland have been described by Van Wijk. The coastal areas from which samples were taken on the writers' survey consisted chiefly of red-brown clay-loams over raised coral and brown-yellow clays. In addition, one alluvial soil and two coral sand areas were examined. The soils were all derived from calcareous material except the alluvial soil, which appeared to have been formed from volcanic material. The occurrence of small quantities of magnetite in the sand fractions of the soils further inland, indicated that some volcanic material from the high ranges, which form the backbone of New Ireland, probably had been washed down. There was no evidence that this material was associated with the formation of the coastal soils.

On a typical plantation, palms are planted from the edge of the coastal limestone cliffs to the foothills, which may lie from one mile to four miles inland. The soil on the coast is a shallow red-brown loam over raised coral, varying in depth from a few inches to two or three feet. The fissured nature of the parent coral leads to large variations in soil depth over a short distance. Free coral limestone occurs on the surface and throughout the profile, ensuring the soil is kept in a lime-saturated flocculated condition. Drainage of excess water proceeds rapidly through holes in the limestone into underground streams. Palms on this soil type are usually, but not always, in a healthy condition. They suffer occasionally from overdrainage in dry periods. However, the symptoms on chlorotic palms are similar to those further inland on the slower-drained soils.

Progressing inland, the soil increases in depth and there is much less influence of the underlying coral on the soil characteristics. The soil colour changes to orange or yellow due to the substitution of the clay bases by hydrogen, slower drainage conditions and consequently hydration and reduction of the iron minerals. The palms on these more acid soils are very often declining in pro-

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duction and showing chlorosis varying in degree from slight to very severe. From examination of the soils after heavy rain it did not appear that impeded drainage was a primary cause of the decline of palms on this type of soil.

There is seldom an abrupt change either in the field characteristics of the soils or in the degree of chlorosis of the palms but changes occur gradually through intermediate stages. Occasionally healthy productive palms are to be found growing well inland on alluvial and volcanic soils and also on soils derived from soapstone. On some parts of the coast there exists a coral sand fringe where coconut growth is usually satisfactory, providing palms have access to the moving water table.

Descriptions of the Visual Symptoms.

The symptoms of nutrient disorder in coconut palms are evident on substantial areas of almost all plantations between Kavieng and Namatanai, and in general, they are in their severest form on those parts of the plantations furthest from the beach. The majority of plantations employ a cover crop, usually *Pueraria,* which invariably displays symptoms where palms are unthrifty. Symptoms are apparent also in some areas in *Leucaena glauca* seedlings, *Centrosema, Tephrosia candida,* corn and *cacao.*

Coconut Palms: In the earlier stages the symptoms occur as a slight yellowing of the margin and tips of leaflets of the lower fronds. The lengths of the fronds and leaflets are less than those of healthy palms, and there are noticeably fewer fronds and nuts.

At the severest stage, the leaflets of the old and some young fronds are almost completely yellow to orange-yellow, and even leaflets of the most recent fully-expanded fronds show some chlorosis. Leaflets and fronds are much reduced in size, being a third to a half of those of healthy palms, and older fronds are prematurely shed, leaving a small number of upright fronds. Numerous small necrotic spots cover the chlorotic tissues of the leaves. Palms so affected are stunted and generally two-thirds or less than the height of healthy palms. The number of nuts carried ranges from nil to 10. Typical chlorosis symptoms of coconut palms and fronds are illustrated in Plates 1 to 4.

Pueraria: The symptoms show as a marginal and interveinal yellowing of the leaves, the extent of the chlorosis increasing with the age of the leaf, the oldest sometimes showing marginal scorching. The leaves are much smaller than normal and tough in texture. The growth of *Pueraria* is greatly restricted in areas where the palms are very poor, and in some instances is barely adequate to cover the soil. Plate 5 shows a general view of *Pueraria* cover crop with severe chlorosis. A chlorotic *Pueraria* leaf is shown in Plate 6.

Leucaena glauca: Symptoms occur in *Leucaena* seedlings only in areas where palms are very unthrifty. They show as a marked stunting in growth and a tip scorch of the leaflets. No scorching was evident on *Leucaena* which was more than four feet tall.

Centrosema and Tephrosia: A marginal yellowing, particularly of the older leaves, was observed in these legumes when found growing in poor areas (see Plate 8).

Corn: In one area where corn was grown, the symptoms of marginal leaf scorch, interveinal chlorosis, undeveloped deformed ears, decaying root and nodal tissue were clearly evident.

Cacao: Marginal leaf scorch in *cacao* is widespread, but unlike the symptoms appearing in palms, *Pueraria* and *Leucaena,* it is more severe and prevalent near the coast than inland. The scorch takes the form of a grey to almost white necrosis of the marginal tissues of about the sixth leaf from the terminal and increasing in severity down the branch. A slight yellow mottle occurs in the area between the necrotic margin and healthy centre tissue of the leaf. A typical example of *cacao* leaf scorch is shown in Plate 9.

Methods of Sampling and Analysis.

(*a*) SAMPLING.

Selection of Sampling Sites: Where possible, palms of uniform appearance were chosen as sites suitable for sampling. Five ratings of productivity based on an estimate of the average number of nuts carried were made, and 23 sites spread over the five groups were selected for sampling.

	Productivity Rating.	Nuts/palm.
1	High	60 +
2	Fairly high	40 — 60
3	Medium	20 — 40
4	Low	5 — 20
5	Very low	0 — 5

Nut Waters: At each site, mature fallen nuts from 10 palms were collected, and a sample from each nut preserved with a few drops of formaldehyde in a specimen tube.

Husks: Samples of husks from the above nuts were bulked into one sample.

Fronds: About 20 leaflets from the mid-portion of the youngest fully-expanded frond were taken from a single palm representative of the site.

Pueraria: The third leaf from the terminal was taken and collection made over an area of 10 yards square.

Leucaena: Terminal leaves were collected.

Cacao: The third leaf from the terminal of hardened flushes was selected. Twenty leaves from five trees represented one sample.

Soil: At each site, samples of 0-4 in., 4-8 in. were taken.

(*b*) Analysis.

Nut Waters: Samples were diluted and K, Na, Ca were determined on a Beckman D.U. Flame Spectrophotometer by the method of Southern (1956). The concentration of P was determined colorimetrically on the diluted solution with an E.E.L. absorptiometer. The concentration of Cl was found by titration of a 10 ml. aliquot of the undiluted nut water with N/10 $AgNO_3$.

Leaves and Husks: Samples were oven-dried, ground, ashed at 500°C. and extracted with 1 + 4 HCl on a water bath. After dilution, analysis for K, Na, Ca, P was made as above. Analysis for N was made by the Kjeldahl method. Mn was determined by the permanganate method.

Soils: Samples were air-dried and passed through a 2 mm. sieve; pH and conductivity were determined on a 1 : 5 soil water extract. The exchangeable cations were determined directly on a Beckman Flame Spectrophotometer after leaching with normal ammonium acetate. Total exchange capacity was determined by the ammonia absorption method. The Olsen and Truog (modified) methods using 0.5 M $NaHCO_3$ and 0.01N H_2SO_4 respectively to extract phosphorus gave an indication of the phosphate status of the soil. Total N was determined by the Kjeldahl method. Further fractionation of the potassium in the soil was made by boiling separate portions of the soil with N HNO_3 and concentrated HCl. Mechanical analyses were carried out by utilizing a plummet balance after pre-treatment of the soils.

Experimental Results.

The 23 sites sampled between Kavieng and Namatanai were located on coral-derived soils with the exceptions of Site 3 (an alluvial of volcanic origin), Site 12 (coral sand), Site 20 (slightly-raised coral sand). Samples from palms making vigorous growth on immature volcanic ash soils, Sites 1 and 2, have been analyzed to give comparative data in the high-producing categories.

The summary of the analysis of nut waters, fronds, husks and soils is given in Tables I, II and III.

TABLE I—PLANT ANALYSIS

Location Site No.	PRODUCTIVITY RATING nuts/palm	NUT WATER (p.p.m.)			No. of Analyses	FROND (Per cent. dry basis)					HUSK Per cent. in ash		Per cent. Ash	APPEARANCE
		K	Na	Ca		K	Na	Ca	N	P	K	Na		
1.	High	3000	78	231	5	2.10	.02	.16	....	....	35.7	.66	4.21	Palms healthy in appearance making vigorous growth.
2.	60+	2380	82	171	25	....	....				....	....	....	
3.		2531	159	204	10	....	....				35.3	10.1	3.71	
4.		2503	218	272	10	....	....				36.9	7.3	3.43	
5.	Fairly high 40-60	2065	422	313	10	....					....	....	....	Palms healthy.
6.	Medium	1378	631	361	10	1.10	.42	.11	1.67	.16	11.8	25.4	2.95	Palms generally healthy in appearance, some have signs of chlorosis.
7.	20-40	1316	673	200	10	.83	.54	.11	2.02	.12	13.3	20.1	3.11	
8.		1268	676	177	10	.46	.45	.22	2.10	.18	11.5	25.8	2.66	
9.		1225	1005	272	12	....	....	....	....	....	....	....	....	
10.		1215	1065	235	10	.68	.55	.13	1.99	.13	....	....	....	
11.		1063	1034	232	10	....	....	....	....	....	....	....	....	
12.		1088	865	342	10	....	....	....	....	....	5.6	30.5	2.66	
13.		820	954	218	10	....	....	....	....	....	7.1	24.5	2.80	
14.		607	976	199	10	....	....	....	....	....	6.0	28.4	2.86	
15.	Low	840	689	186	10	.52	.65	.25	2.11	.17	11.7	22.6	3.60	Palms unthrifty, fronds small and sparse, older fronds chlorotic.
16.	5-20	998	785	286	10	....	....	....	....	....	16.4	18.2	2.75	
17.		752	977	223	10	....	....	....	....	....	5.3	25.3	2.97	
18.		687	902	284	8	....	....	....	....	....	....	....	....	
19.		681	904	212	9	.46	.47	.16	2.16	.18	3.8	29.4	3.40	
20.		672	926	227	10	....	....	....	....	....	5.8	30.0	3.12	
21.		380	1080	255	10	.49	.43	.24	2.18	.15	5.2	26.7	3.51	
22.	Very low	530	858	236	18	.28	.47	.20	2.05	.15	19.7	15.2	2.89	Palms very unhealthy, some dying.
23.	0-5	393	956	232	13	.26	.72	.13	2.04	.12	3.8	24.7	2.78	
24.		366	753	176	11	.10	.47	.25	1.74	.13	7.6	21.4	2.62	Palms are stunted, fronds very small and few in number, severe chlorosis.
25.		364	795	201	14	.24	.29	.21	1.71	.11	....	....	....	

TABLE II—ANALYSIS OF SOILS

Location Site No.	Productivity Rating Nuts/Palm	Depth ins.	pH	Soluble Salts per cent.	Exchangeable Cations m.e. per cent.					Cation Exchange Capacity m.e. per cent.	Bate Saturation per cent.	P2O5 Olsen Truog p.p.m.		Total N per cent.	Clay per cent.	Description
					Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Total							
3	High	0-4	5.6	.029	25.0	8.0	.52	.50	34.0	38.8	88	6	20	.38	29	Alluvial soil volcanic origin.
	60 + ...	4-8	6.0	.021	24.3	8.9	.30	.46	34.0	36.8	92	4	14	....	33	
6	Medium	0-4	7.4	.078	*	2.4	.58	.60	*	25.8	100	16	32	.92	36	Shallow red-brown clay loam.
8	20-40	0-4	6.1	.063	19.9	6.2	.54	.53	27.2	27.0	100	34	24	.44	45	Deep red-brown clay loam.
		4-8	6.1	.065	16.1	3.6	.51	.59	20.8	21.6	96	23	25	....	60	
9		0-4	6.2	.072	32.5	3.3	.57	.80	37.2	....	....	35	18	.52	63	Shallow red-brown clay loam.
10		0-4	6.5	.057	31.6	10.6	.65	.50	43.4	....	....	35	30	.66	55	Shallow red-brown clay loam.
		4-8	6.9	.059	40.0	5.3	.37	.51	46.4	....	....	20	16	....	60	
15	Low	0-4	5.3	.034	19.9	3.6	.47	.57	24.5	30.0	82	14	14	.46	63	Red brown-yellow clay.
		4-8	5.2	.012	14.7	0.9	.25	.53	16.4	....	....	18	17	....	71	
16	5-20	0-4	5.7	.038	19.8	2.6	.44	.64	23.5	25.9	91	10	15	.54	70	Shallow red-brown clay.
		4-8	5.7	.028	14.4	1.3	.26	.60	18.8	21.1	79	6	4	....	72	
26		0-4	5.8	.059	13.8	4.0	.54	.48	16.6	21.4	88	27	16			Red brown-yellow clay.
		4-8	5.7	.040	9.0	2.1	.34	.40	11.8	....	....	14	16	....	78	
19		0-4	5.9	.029	17.8	3.0	.28	.50	21.6	23.5	92	30	22	.37	67	Shallow red-brown clay loam.
		4-8	5.7	.023	13.3	1.6	.30	.59	15.8	18.6	85	29	25	....	72	
22	Very low	0-4	5.3	.032	21.9	2.8	.32	.57	25.6	32.3	79	20	10	.66	62	Red brown-yellow clay.
	0-5	4-8	5.1	.016	16.2	1.0	.20	.59	18.0	29.0	62	5	8	....	67	
		0-4	5.5	.045	17.2	3.4	.43	.64	21.7	25.5	85	12	10	.41	67	Red brown-yellow clay.
		4-8	5.6	.041	13.0	1.3	.37	.46	15.1	18.9	80	8	11	....	73	

1. All results are expressed on an air dry basis.
2. As no preliminary leaching for soluble salts was carried out, these figures include small amounts of Soluble Salts.

* Calcium carbonate present.

TABLE III—POTASSIUM CONTENTS OF SOILS

Location Site No.	Productivity Nuts/Palm	Depth ins.	K. Soluble in conc. HC1, m.e./100g	K Soluble in N HNO_3, m.e./100g	Exchangeable K m.e./100g
3.	High	0-4	4.40	1.90	.52
	60 + ...	4-8	4.55	1.40	.32
6.	Medium	0-4	1.65	1.15	.58
8.	20-40	0-4	1.50	.75	.54
		4-8	1.40	.75	.51
9.		0-4	1.35	.65	.57
10.		0-4	1.45	.95	.65
		4-8	1.20	.60	.37
15.	Low	0-4	1.45	.65	.47
	5-20	4-8	1.40	.55	.25
16.		0-4	1.35	.55	.44
		4-8	1.15	.35	.26
26.		0-4	1.25	.75	.54
		4-8	1.35	.60	.34
19.		0-4	1.20	.50	.28
		4-8	1.25	.55	.30
22.	Very low	0-4	1.05	.45	.32
	0-5	4-8	1.20	.50	.20
24.		0-4	1.25	.60	.43
		4-8	1.30	.50	.37
Average 0-4 inches.—					
High Productivity			4.40	1.90	.52
Medium Productivity			1.49	.90	.58
Low Productivity			1.31	.61	.43
Very Low Productivity			1.15	.52	.37

TABLE IV

Location Site No.	Distance Inland (Yds.)	NUT WATER (ppm)					No. of Analyses	FROND (Per cent. dry basis)						HUSK (Per cent. in ash)			PUERARIA (Per cent. dry basis)			
		K	Na	Ca	P	Cl		K	Na	Ca	N	P	Mn (ppm)	K	Na	Per cent. Ash	K	Na	Ca	P
7.	10	1316	674	200	84	2177	10	.83	.54	.11	2.02	.12	50	13.3	20.1	3.11	1.64	.02	1.40	.20
13.	140	820	954	218	121	2147	10	....	....	....	....	....	....	....	....	....	....	....	....	....
21.	200	380	1080	255	125	2080	10	.49	.43	.24	2.18	.15	74	5.2	26.7	3.51	1.44	.02	1.40	.28
23.	350	393	956	232	143	1896	13	.26	.72	.13	2.04	.12	85	3.8	24.7	2.78	.52	.01	1.28	.30
25.	800	364	795	201	128	1952	14	.24	.29	.21	1.71	.11	350	....	....	....	.44	.01	1.31	.25
For comparison—health palms on volcanic soil.																				
1.	400	3000	78	231	104	1900	8	2.1	.02	.16	....	....	60	35.7	.66	4.21				

FIELD DESCRIPTIONS.—

7. Palms fairly good, up to 40 nuts/palm, fronds large, no chlorosis. *Pueraria* and grass cover showing no symptoms.

13. Palms variable, 20-40 nuts/palm, little to no chlorosis in older fronds. No symptoms in *Pueraria*.

21. Palms very variable, 15-30 nuts/palm, distinct yellowing of lower fronds. No symptoms in *Pueraria*.

23. Palms very poor, 0-5 nuts/palm, severe chlorosis of old and young fronds, fronds small and sparse. *Pueraria* very chlorotic and stunted.

25. Palms extremely poor, some dying, 0-5 nuts/palm, severe chlorosis of all fronds, palms stunted, fronds very small and sparse. *Pueraria* very chlorotic, inadequate soil cover.

To investigate the marked increase in the debilitation of the palms with increasing distance from the shore, a traverse was run along a line of palms from the shore to 800 yards inland. The topography and soil changes of the plantation chosen for the traverse were typical of many East Coast plantations. At the shore a raised coral terrace, some 60 feet above sea-level, gradually slopes down away from the sea for a distance of about a mile to the foothills. The soil near the shore is shallow, slightly-acid to neutral red-brown clay-loam, changing to a deep, acid, yellow-brown clay further inland. Five sites on the traverse were selected for sampling. The results and field descriptions are given in Table IV.

A study of the data set out in Tables I to IV shows that the potassium level in the palms and soil is closely related to palm productivity and the deficiency symptoms.

(*a*) NUT WATER ANALYSIS.

Potassium : Under conditions of an abundant potassium supply as in the soils derived from volcanic ash (3 to 6 m.e. per cent. exchangeable K^+) (Graham and Baseden 1956) the potassium content in mature fallen nuts from very productive palms ranges from 2300 to 3000 p.p.m. K. This appears to be about the maximum level that occurs under natural conditions. As would be expected, a higher level occurs in actively-developing nuts and rises to 4000 p.p.m. K in the smallest nuts on the palm.

On the acid soils derived from coral (0.2 to 0.4 m.e. per cent. exchangeable K^+) where palms are carrying from nil to five nuts each, the average potassium level in the water of mature fallen nuts is less than 400 p.p.m. K, some individual nuts being as low as 50 p.p.m. K.

Between these two extremes, the productivity of the palms, measured as the number of nuts carried, bears a close relationship to the level of potassium in the nut water.

In Graph I, the potassium concentration in the nut water is shown plotted against the productivity of palms at each of the 25 sites. The average productivity of the 60+ nuts per palm group has been arbitrarily set at 70.

The regression line for these data is :

$$Y = .0281\,X - 4.86$$

where Y = average number of nuts per palm at each site,

X = p.p.m. K in the nut water (average of approximately 10 nuts from each site).

The correlation coefficient is 0.95.

From the data summarized in Graph I, a tentative scale has been drawn up to indicate the potassium status of palms in the areas investigated.

K (p.p.m.) (in mature nuts)	PRODUCTIVITY (nuts per palm)	SYMPTOMS	POTASSIUM STATUS INDICATED
2,300-3,000	60+	None	High.
1,600-2,300	40-60	None	Sub-optimal.
900-1,600	20-40	Chlorosis of lower fronds in some cases.	Deficient.
350-900	5-20	Fronds small and sparse, older fronds chlorotic.	Very deficient.
0-350	0-5	Palms stunted, some dying. Fronds very small and sparse. Severe chlorosis of old and young fronds.	Extremely deficient.

Sodium : A striking feature of the nut water analysis is the substantial uptake of sodium when there is a deficiency of potassium.

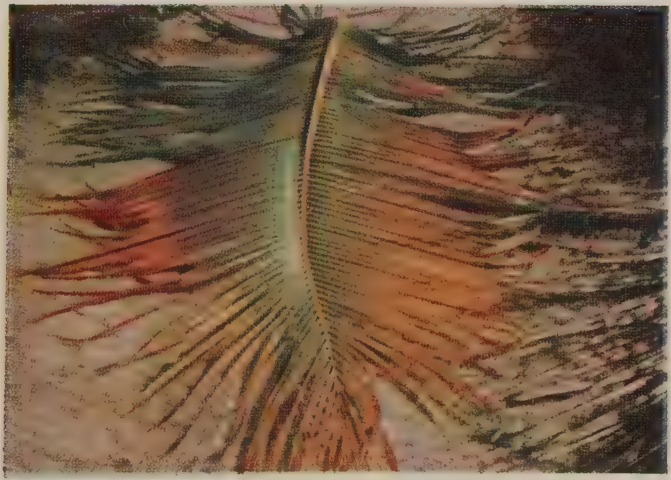
On the potash-adequate volcanic ash soils, the sodium in nut waters is generally less than 100 p.p.m. Na, regardless of proximity to the sea. Where potash is deficient on the acid coral-derived soils and the level in the nut water falls below 1,000 p.p.m. K, sodium rises to 800-900 p.p.m. Na.

In New Ireland, where the more deficient soils are further inland, the situation arises that palms nearer the sea have a lower sodium content in the nut water.

Plate 1.—A typical declining plantation on the east coast of New Ireland.

Plate 2.—Coconut Palm showing chlorosis caused by potassium deficiency. Note the short fronds and low nut production.

Plate 3.—Chlorosis symptoms on a coconut palm frond.



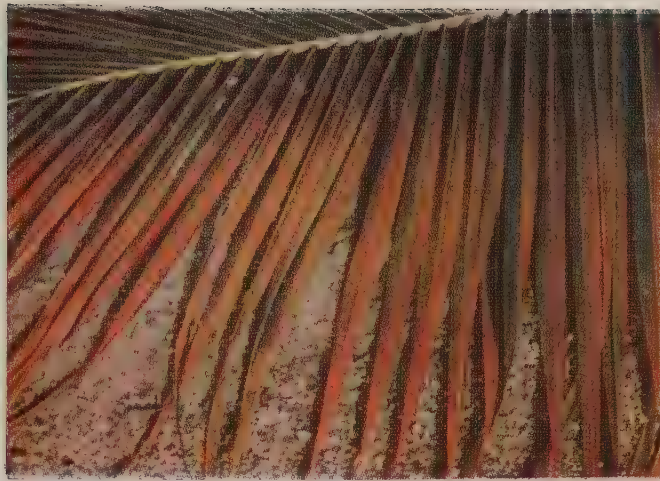


Plate 4.—Close-up view of typical chlorosis symptoms on a coconut palm frond.

Plate 5.—General view of Pueraria cover crop showing severe chlorosis in the older leaves.

Plate 6.—Pueraria leaf from the field showing marginal chlorosis caused by Potassium deficiency.

Plate 7.—Pot experiment using Pueraria and topsoil from a typically poor area of New Ireland. Treatments without potassium showed typical chlorosis symptoms.

Plate 8.—General view of cover crop predominantly Centrosema, with marginal chlorosis.

Plate 9.—Leaf scorch in cacao. The older leaves are affected with a greyish-white marginal necrosis.

The relationship between sodium and and potassium is shown in Graph II, where each point represents the average of the analysis of approximately 10 nuts from a site.

The line of regression is given by the equation :

$$Y = 1158 - .360 X$$

where Y = p.p.m. Na in the nut water
X = p.p.m. K in the nut water
The coefficient of correlation is —0.88.

It is noticeable that the summation of the chemical equivalents of sodium and potassium tends to be constant in the medium to high productivity groups, indicating the ability of mutual replacement. However, there in no evidence that sodium can replace potassium in its function as a plant nutrient.

The following figures show the average potassium and sodium contents of nut waters in each of the five productivity groups, converted to milliequivalents per litre.

Productivity (nuts per palm)	K^+	Na^+	K^+ plus Na^+
60+	66.7	5.8	72.5
40-60	52.8	18.4	71.2
20-40	28.4	42.4	70.8
5-20	18.3	39.0	57.3
0-5	10.5	36.6	47.1

From the foregoing it would appear that a high sodium content (800-900 p.p.m. Na) may be taken as indirect evidence of a potassium deficiency.

Calcium : The calcium concentration of nut water tends to be constant, regardless of whether samples come from palms on coral sand (pH 8.4) or acid coral-derived soil (pH 5.0).

Chloride : The main inorganic anion present in nut water is chloride (approximately 2,000 p.p.m. Cl) and the level varies very little according to the distance from the sea. The chloride content is quite unrelated to sodium content. On volcanic ash soil, low sodium values (less than 100 p.p.m. Na) are associated with about 1,900 p.p.m. Cl at both 400 yards and two miles from the sea. In New Ireland, samples from near the shore and half a mile inland differ very little in chloride content (2,177 to 1,952 p.p.m. Cl), although the sodium level varies considerably (see Table IV).

Phosphorus : As shown in Table IV, the poorer palms further inland have a relatively higher level of phosphorus in the nut water. These levels (120-140 p.p.m. P) are higher than those found in productive palms on other soil types.

At Site 7, where the level falls to 84 p.p.m. P, the coral is exposed in many parts with only pockets of soil occurring in the crevasses.

Areas such as this give relatively good, but often still less than optimum production. The adequacy of phosphorus in these areas is under investigation.

(*b*) Frond Analysis.

Potassium : The figures in Table I show that the potassium content of the fronds ranges from 2.1 per cent. K in good palms to as low as 0.10-0.28 per cent. K in the poorest palms. As with the nut water values, there is a close relationship between productivity and potassium content. The average values in each of the groups are as follows :—

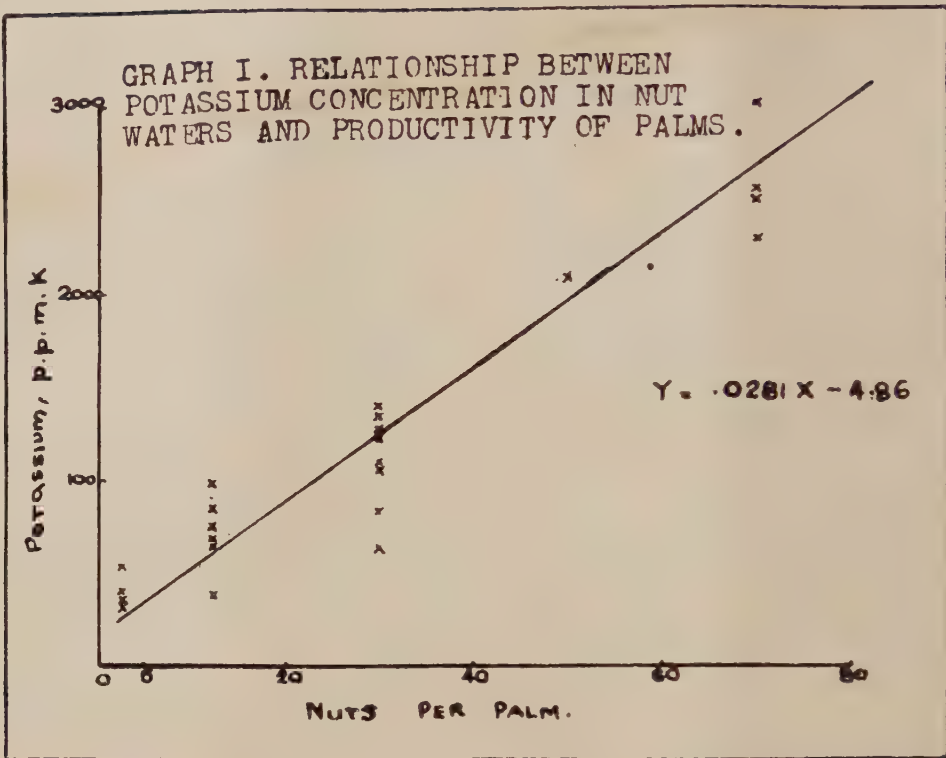
	Productivity	K per cent. (dry basis)
1	High	2.1
2	Fairly high	—
3	Medium	.77
4	Low	.49
5	Very low	.22

From the analysis and field notes it appears that symptoms of chlorosis sometimes occur when the level of potassium is below 0.8 per cent. K, and are invariably present when the level falls below 0.5 per cent. K.

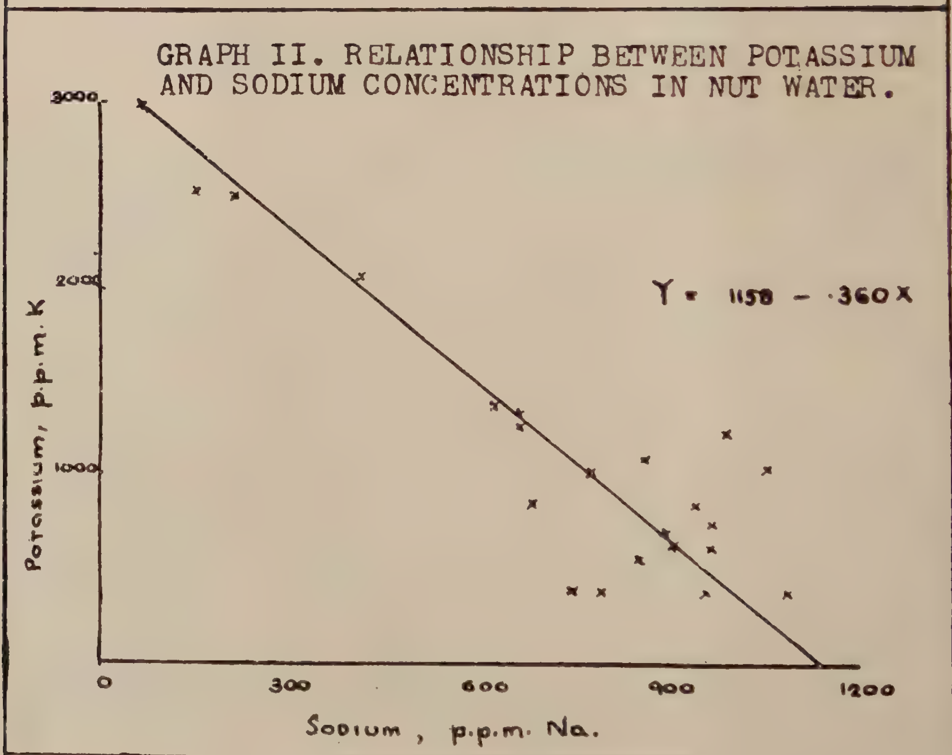
Prevot and Ollagnier (1957) place the critical level of potassium in fronds at 0.45 per cent. K.

Sodium : The uptake of sodium is considerable in the medium, low and very low productivity groups. Such a high content would be considered toxic in many plants, but in the case of the coconut palm it appears that sodium is only absorbed in quantity as a compensatory action when there is a potassium deficiency.

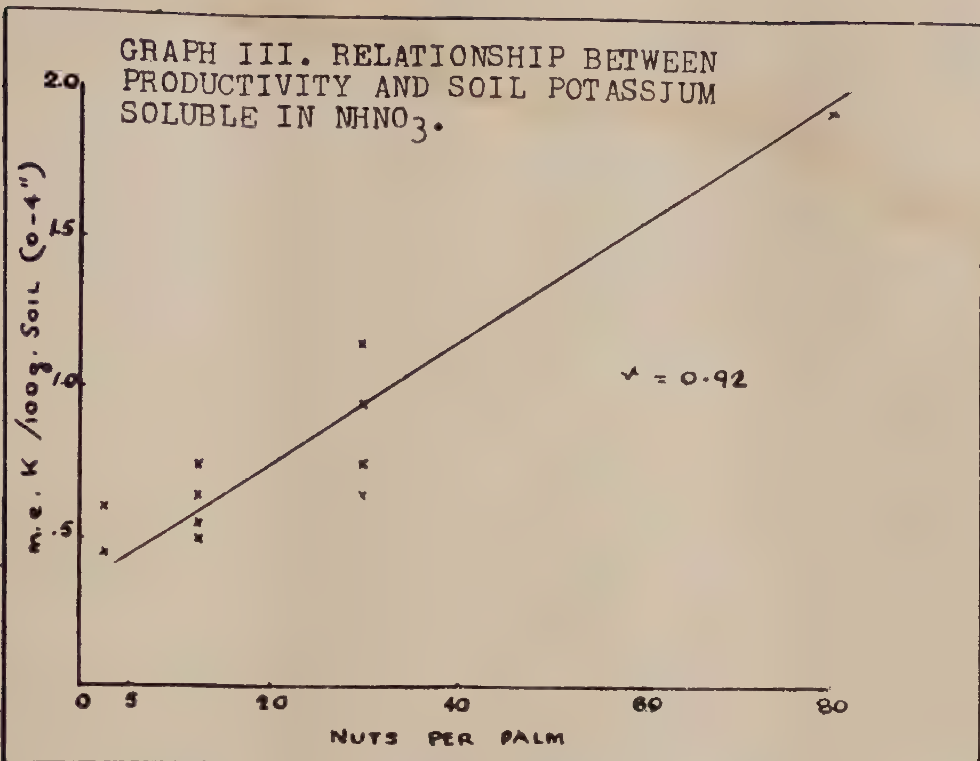
Calcium : The calcium content of the fronds shows little variation that can be related to the productivity of the palms or the amount of exchangeable calcium in the soil.



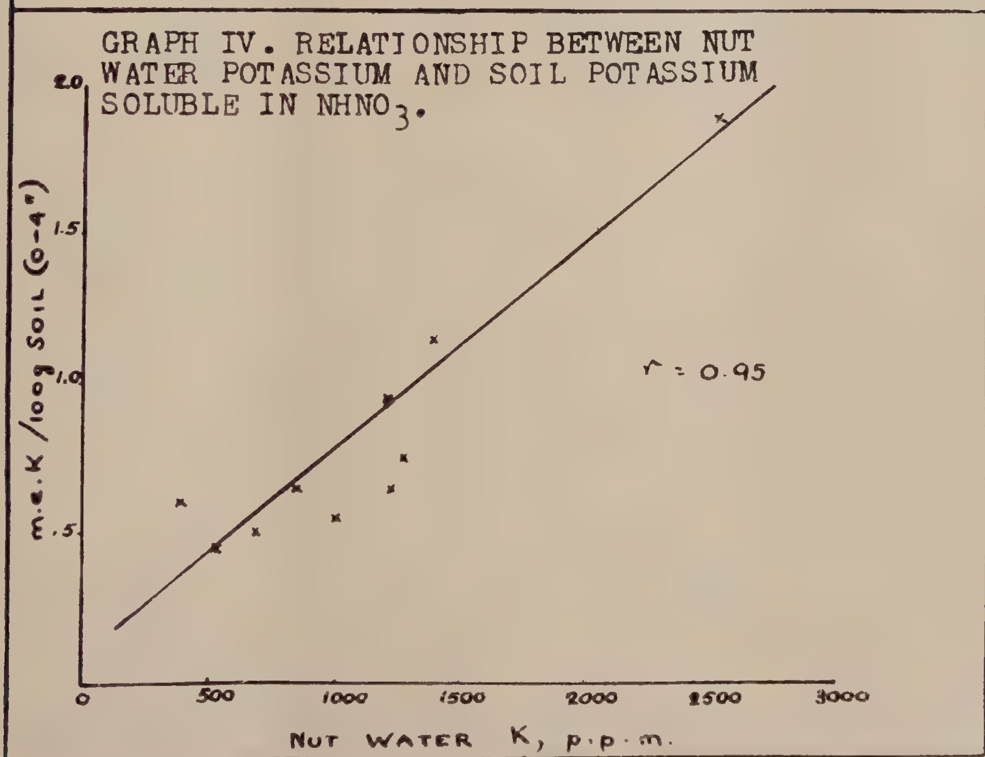
GRAPH I. RELATIONSHIP BETWEEN POTASSIUM CONCENTRATION IN NUT WATERS AND PRODUCTIVITY OF PALMS.



GRAPH II. RELATIONSHIP BETWEEN POTASSIUM AND SODIUM CONCENTRATIONS IN NUT WATER.



GRAPH III. RELATIONSHIP BETWEEN PRODUCTIVITY AND SOIL POTASSIUM SOLUBLE IN $NHNO_3$.



GRAPH IV. RELATIONSHIP BETWEEN NUT WATER POTASSIUM AND SOIL POTASSIUM SOLUBLE IN $NHNO_3$.

Nitrogen: A level of approximately 2.0 per cent. N, which is considered adequate, was found in fronds of palms in the medium, low and very low productivity groups, with exceptions at three sites. The lowest value of 1.67 per cent. occurred at Site 6, a coral sand where little organic matter had accumulated and conditions were too alkaline for the establishment of the usual leguminous cover crops. The other low values of 1.74 and 1.71 per cent. N occurred at Sites 24 and 25 where the *Pueraria* cover was so restricted in growth, due to potassium deficiency, that it probably was contributing very little nitrogen to the soil.

The nitrogen levels of palms in the areas investigated are generally high, giving evidence of the beneficial effects of maintaining a good leguminous cover. Palms on volcanic ash soil with no cover crop contain only about 1.7 per cent. N in the fronds. The critical level for nitrogen in fronds is given as 1.70 per cent. N by Prevot and Ollagnier.

Phosphorus: The average phosphorus content of fronds of palms in the medium, low and very low productivity groups is 0.15, 0.17, 0.13 per cent. P respectively. It is difficult to assess how marked an effect a severe deficiency of potassium has on the phosphate level, but, as far as can be judged, the contents found would not indicate a deficiency. Prevot and Ollagnier give the critical level as 0.10 per cent. P.

Manganese: There is a tendency towards higher contents of manganese in the fronds of palms from the poorer areas on the more acid soils. This is shown in Table IV.

It has been found that sun drying of soils preparatory to analysis releases a considerable amount of exchangeable manganese (up to 250 p.p.m. Mn^{++}) from the acid coral-derived soils. The same soils release less than 2 p.p.m. Mn^{++} if not sun dried.

The analysis of fronds and leaves of indicator plants gives no evidence of manganese toxicity under normal rainfall conditions, but the possibility of damage from excess manganese during exceptionally dry periods is still being investigated.

(c) Husk Analysis.

Potassium and Sodium: The percentage of potassium in the husk ash shows a considerable decrease which is related to the decline in productivity of the palms (see Table I). There is also a corresponding increase in the sodium content.

The following figures show the extreme variation that can occur in husks from potash-adequate volcanic soil (A) and deficient soil (B).

	A	B
Weight of dry husk (gm.)	414.0	270.0
Ash per cent.	4.21	3.78
K per cent. in ash	35.7	3.79
Na per cent. in ash	0.66	28.1
Total K content per husk (gm.)	6.2	0.39

The significance of these figures in relation to management practices is discussed later.

(d) Soil Analysis.

A fairly complete analysis of soil samples from 11 of the 23 sites was undertaken and the results are shown on Tables II and III. While most attention was paid to the potassium status of the soil, factors influencing this status, e.g., exchange capacity and mechanical composition, also were examined.

The pH of the soils varies from slightly alkaline on some of the red-brown loams over raised coral to markedly acid on the deep brown-yellow clays further inland. The pH correlates well with the percentage base saturation which varies from 62 to 100 per cent. The total exchange capacity of the coral-derived soil is fairly constant, and relatively high, probably due to the high organic matter content of the topsoil. The total nitrogen content of the soils, most of which are under heavy legume cover, is high; and leaf analysis confirms the view that no serious nitrogen deficiency exists throughout the plantations.

The phosphorus status of most of the soils is fairly low by the two methods used for determining available phosphorus. However, coconuts have a low requirement for phosphorus and the analysis of plant samples shows that phosphorus is not likely to be a seriously limiting nutrient. Further investigations are being carried out to define more clearly the P status of these soils.

As expected, calcium is the dominant cation in the exchange complex and exchangeable magnesium is also present in normal quantities. The exchangeable potassium content is not high in any of the soils and examination of Table III shows that it can roughly be correlated with the degree of productivity of the palms on coral-derived soils. Further differentiation of the potassium content of the soil was made by boiling with (*a*) N HNO_3 and (*b*) conc. HCl. The former was used to extract the less available potassium as well as exchangeable potassium, while the latter should give results approximating the total potassium content of soils derived from limestone.

A good relationship was found to exist between the productivity and condition of palms and nitric acid-extractable potassium (Graph III). On some of the poorer soils this potassium is estimated to be less than 200 lb. per acre foot of soil and as an acre of healthy coconuts may remove annually up to 100 lb. of potassium, it is not surprising that many palms are showing gross deficiency symptoms. The total reserves of potassium on many of the better soils are less than 1,000 lb. per acre foot of soil and continued healthy growth does not appear possible as, under normal plantation practices, little potassium is returned to the soil.

There is good correlation between the potassium contents of the soil, particularly the nitric acid-extractable potassium, and the potassium content of the coconut water (Graph IV). No significant relationships are apparent between the decline in productivity in palms and Ca : K ratio or potassium percentage of the exchange complex. Nor is there evidence in soil analyses of any marked accumulation of sodium, either in the soluble or exchangeable form, to account for the large amounts absorbed by the palms.

It can be concluded from soil analyses and their relationship to palm production that :—

(*a*) The available potassium status of the coral-derived soils is low, especially on the areas of most decline and chlorosis;

(*b*) Coral-derived red and yellow clay soils containing less than 0.6 m.e. per cent. of exchangeable K and less than 1.0 m.e. per cent. of K soluble in normal nitric acid can be regarded as unlikely to produce optimum yields of coconuts; and

(*c*) The potassium reserves of most of the soils are inadequate for the continued healthy growth of coconuts without further additions of potassium.

(e) Pueraria Symptoms.

In the field there is ample evidence of close association between the occurrence of symptoms in *Pueraria* and the vigour of coconut palms in the same area. To assess the value of *Pueraria* as an indicator plant, leaves from several sites were analyzed. Pot tests and field applications of fertilizer were also made.

Leaf Analysis: From the descriptions and figures in Table IV it will be seen that, on a traverse in from the shore, the potassium status of *Pueraria* parallels that of the palms and falls progressively from 1.64 to 0.44 per cent. K. No marked change occurs in the sodium, calcium or phosphorus levels.

Samples collected from Sites 16, 19, 22, 23, 25, where palms were poor and symptoms occurred in the *Pueraria*, had potassium contents ranging from 0.44 to 0.60 per cent. K. Samples from 7 and 11, where there were no symptoms, contained 1.64 and 2.70 per cent. K.

Pot Tests: Treatments of no fertilizer, N, N+P, N+P+K, and N+P+K+ trace elements showed that the symptoms developed only in pots without the potassium application. (See Plate 7.)

Fertilizer Application in the Field: Application of KCl in the field gave complete removal of the chlorosis as well as a substantial increase in vigour of the *Pueraria* after a few months.

It is evident from these investigations that the symptom illustrated in Plates 5 to 7 is due to potassium deficiency and that *Pueraria* can be considered a useful indicator plant for detecting a deficiency of potash in soils.

(*f*) Leucaena Symptoms.

Leaf samples from four locations where there was leaf tip scorch on *Leucaena* seedlings had potassium contents of 0.51-0.75 per cent. K. Samples from seedlings with no scorch contained more than 1.0 per cent. K.

Applications of potash in the field removed the symptoms and improved growth, substantiating the conclusions from leaf analysis that the symptom was an indication of potassium deficiency.

(g) Cacao Symptoms.

Marginal leaf scorch occurs frequently in *cacao* near the sea, but seldom further inland. Leaf samples from eight sites with scorch showed that a negligible amount of sodium was present in the young leaves (0.02 per cent. Na), and the potassium content ranged from 0.38-1.06 per cent. K. Samples from six sites with no scorch also were low in sodium and contained 0.96-1.86 per cent. K. Although the possibility of excessive amounts of salt in the older leaves which show the symptom is not excluded, it is evident that the potassium status of the trees at all sites is low. The average content in 30 samples from thrifty trees on volcanic ash soil was found to be 2.55 per cent. K. A level of 2.12 per cent. K is given for "good standard plots" in Trinidad (McDonald 1934).

Reduced uptake of potassium by trees nearer the shore, because of the lower K/Ca ratio in these soils and increased sensitivity to salt due to the low potassium status of the trees, are factors still under investigation in relation to the cause of the marginal scorch symptom.

The phosphorus contents of samples from the 14 sites gave an average value of 0.18 per cent. P (range 0.14-0.22 per cent. P) which is slightly below 0.219 per cent. P recorded for "good standard plots" in Trinidad, and 0.21 per cent. P from 30 samples from healthy *cacao* on volcanic ash soil.

Discussion and Conclusions.

It has been shown that the considerable range of productivity (from less than five to more than 60 nuts per palm) occurring among palms on coral-derived soil is closely related to the potassium levels found in nut waters, husks, fronds and soils. The intensity of symptoms such as chlorosis, smallness and sparseness of fronds is similarly related to the potassium level.

The general pattern of distribution of healthy and poor palms on the east coast of New Ireland can be explained in terms of the potassium status of the palms and the change in soil characteristics. The better palms with a higher potassium status occur on a narrow coastal strip of shallow, neutral to slightly acid, red-brown clay-loams, and poorer palms with a low potassium status are located on a much deeper, acid, yellow-brown clay that is present on the inland side of this strip. There is a graduation in soil characteristics (depth, pH, potassium content) and in the potassium status of the palms between these extremes which coincides with a change in productivity.

The analysis of nut water, first used by Salgado (1946), has been shown to be a useful diagnostic method which appears to be capable of indicating not only the presence but, to some extent, the degree of potassium deficiency in coconut palms. From the data in this report, a tentative scale has been drawn up which may prove useful as a guide to the potassium status of palms on other soil types. Preliminary studies have not indicated that there is any marked change in nut water potassium with season, this being due probably to the continuous-bearing nature of the coconut palm and the absence of extreme seasonal variations in the areas investigated. Nut water analysis has a considerable advantage over frond analysis as a diagnostic method for potassium deficiency because of the difficulties of large-scale sampling of fronds.

From frond and nut water analysis there is no indication that phosphorus is connected with the decline of palms.

The nitrogen level in both soil and fronds has been found to be high where good cover crops are established. Most plantations carry adequate cover.

Damage from excessive manganese during exceptionally dry periods might appear to be a possibility, from the evidence that sun-drying of soil samples before analysis releases large amounts of exchangeable manganese from the more acid soils where palms are poorest. Leaf analyses of coconuts, cover crop and *cacao* have given no evidence of excessive manganese uptake during a season of normal rainfall. It is possible that a critical soil moisture level must be reached before manganese is released and that such a level rarely, if ever, occurs in the field. A similar effect of manganese release by air-

drying of red clayey "Lunyu" soils in Uganda has been recorded by Chenery (1954).

The commonly-held opinion that palms perform better near the sea because of the influence of salt either in spray or ground water is not supported by this investigation. The nut water and frond analyses show that the uptake of sodium is greater in those palms which are poorer and further from the sea and is closely and inversely related to the uptake of potassium. The chloride content of nut water appears to be fairly constant (2,000 p.p.m. Cl), irrespective of the potassium or sodium levels or proximity of the sea.

The amount of potassium in husks is of some interest, since the practice of returning husks to the soil is not always adopted. It is worth noting that 6,000 husks from healthy palms contain nearly 100 lb. of potash (K_2O), so that a plantation producing 100 tons of copra annually removes about 10,000 lb. of potash from the soil by way of the husks alone. The potash removal over 30 to 40 years would be considerable and an important depleting factor.

In seed selection for replanting, it is important to consider the food reserves of the nut, since for several months the developing plant relies almost entirely on the nutrients within the nut, and even after root establishment in the soil some roots continue to draw on reserves within the husk. There is 17 times as much potassium in nuts from healthy palms (6.8 gm. K in husk and water) than in nuts from deficient palms (0.40 gm. K), and for this reason alone the collection of seed nuts from deficient areas should be avoided.

Cacao is an important secondary crop being developed on many of the plantations which were investigated, and leaf analysis indicates the potash status is generally low. It must be considered a distinct possibility that, in this crop also, potassium deficiency may in time reveal itself by way of loss in productivity.

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COCONUT EXPERIMENT WORK IN NEW IRELAND.

II. PROGRESS REPORT ON FIELD TRIALS.

By A. E. Charles. *

COMPREHENSIVE fertilizer trials, involving all plant nutrient elements, were laid down on plantation coconuts in November, 1955. Up to June, 1958, a trial on red-brown clay-loam had given no response to any element. A trial on yellow-brown clay loam gave a response to potassium only, but not at an economic level. Further trials, with different rates and methods of application of potassium, are being commenced.

A cultivation trial (disc harrowing and strip ploughing), on an intermediate soil type, gave no response, and it is concluded that generally cultivation is impracticable on these soils.

Introduction.

As a result of the preliminary field survey, it was decided that exploratory fertilizer trials should be laid down on the two main divisions of the clay-loam soils. A cultivation trial also was to be carried out on a typical example of these soils.

A. Fertilizer Trials.

Design of Experiments

The fertilizer trials are comprehensive in nature, involving the materials in the above table.

Fertilizer	Nutrient Element	Rate
Lime	(pH control)	2 tons/acre
Sulphate of ammonia	Nitrogen (N)	4 cwt./acre
Muriate of potash	Potassium (K)	2 cwt./acre
Disodium phosphate	Phosphorus (P)	2 cwt./acre
Magnesium sulphate	Magnesium (Mg)	2 cwt./acre
Copper sulphate	Copper (Cu)	14 lb./acre
Sodium molybdate	Molybdenum (Mo)	1 lb./acre
Trace element mixture (Sh) :		
Sulphate of iron	Iron (Fe)	56 lb./acre
Zinc sulphate	Zinc (Zn)	14 lb./acre
Manganese sulphate	Manganese (Mn)	28 lb./acre
Cobalt sulphate	Cobalt (Co)	2 lb./acre
Borax	Boron (B)	28 lb./acre

The rates quoted are for a dressing to be repeated every two years. Sulphate of ammonia, however, was not applied in a single dressing, but in six-monthly applications each of 1 cwt./acre.

The design is a factorial, a half replicate of 2^7 on plots with and without lime. The individual plots are of a single palm. Thus, 128 palms are included in the trial. With all fertilizers except lime the mixture is spread within a circle extending about four feet out from the base of the palm. This close placement aims at preventing "poaching" of fertilizer by the roots of neighbouring palms. The lime, which is used primarily to reduce acidity, has to be spread over the whole surface of the soil to be effective, hence it is broadcast on larger plots (or sub-blocks) of eight palms each (4 x 2), and these plots are separated by a guard row of untreated palms.

The effect of each fertilizer treatment is assessed in each case by a comparison of the yields of 64 palms which have received the treatment, with 64 not treated with that particular fertilizer. The design of the trial also permits accurate assessment of the effects of two or three fertilizers in combination.

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Yield Recording.

In New Guinea, nuts are harvested after they have fallen to the ground. Hence, with the use of single palm plots, it is not possible to record yield as the actual quantity of copra harvested, since it is impossible to determine with certainty where a fallen nut has come from. In any case, accurate recording of fallen nuts is difficult on a commercial plantation.

The method adopted, therefore, has been the counting of immature nuts on the palms. Only nuts above about three inches in diameter are counted. Losses of crop due to nuts which have reached this size failing to reach maturity are very low under our conditions, and may be ignored. On a healthy palm usually seven to eight bunches of nuts are counted, and these represent the yield over a period of about eight months. Counts are made every six months.

Initially, counting was carried out by native assistants who climbed the palms. However, it was found that the recording could be done more quickly and easily, and with equal or greater accuracy, by counting from the ground with the aid of binoculars. This technique has, therefore, been used for all recording after the first two counts.

Records also were made of the weight of meat in nuts from each palm, where possible. Three nuts were sampled if they could be found, but there were always a number of palms with no nuts under them, so that the data collected were incomplete.

Notes also were made on the appearance of the palms—leaf colour and density and shape of the crown.

Selection of Sites.

The results of the soil survey indicated that the soil types were fairly uniform throughout the whole area, so that fertilizer responses from any typical stand of palms should show what could be expected throughout. The sites selected, therefore, were a typical example of the acid, yellow-brown clay-loam soil and a typical example of the red-brown clay-loam.

In both cases, fairly young plantations (about 25 years old) were selected, for two reasons :—

(*a*) Younger palms are more likely to be in a condition to respond than are older palms.

(*b*) A fairly compact block of palms is needed for a reliable experiment. On the poorer soils, particularly, it would be impossible to find a suitable block on the older plantations, where many palms have died.

Experiments and Results.

(*a*) *Yellow-Brown Clay-Loam.*

Palms on the site selected are typically heterogeneous, varying from rather stunted palms with poorly developed, yellow crowns and few nuts, to quite well grown, green and productive palms. There are very many palms missing, and the trial is therefore spread out rather irregularly over four to five acres. Because of the proportion of palms missing, it is difficult to make a precise estimate of the yield per acre, but at the beginning of the experiment it was about five to six cwt. per annum. Subsequently it fell, as shown in Figure 1. Copra out-turn is about 6,800 nuts per ton.

The first nut counts were made in November, 1955, and the first fertilizer dressing was applied at the same time. Thus, the first set of nut counts is a measure of yield prior to fertilizer application and provides a base with which later yields can be compared by covariance analysis. Nut counts have been repeated at six-monthly intervals and are still being continued.

Results of the nut counts up to the time of writing are shown in Table I. Records of meat weights have not shown any indication of response. The only promising result shown by the nut numbers is to potassium (Figure 2) where the response was shown by analysis of covariance to be significant at the 1 per cent. level on the May, 1957, counts. At that time, also, there was observed an appreciable improvement in appearance of potash-treated palms relative to those which had not received potash, and this evidence of potash deficiency has been amply confirmed by chemical analysis of soils and plant materials.

(*b*) *Red-Brown Clay-Loam.*

This trial is situated on raised coral a few hundred yards inland from the sea. Palms are mostly well grown, healthy in appearance,

TABLE I.

Nut Numbers: Fertilizer Trial on Yellow-Brown Clay-Loam.

——	Nov. 1955	May 1956	Nov. 1956	May 1957	Nov. 1957	May 1958
K_0	3,138	2,626	1,937	1,184	2,058	2,296
K_1	3,174	2,581	2,110	1,731	2,608	2,602
P_0	3.125	2,540	1,912	1,494	2,284	2,348
P_1	3.187	2,667	2,135	1,421	2,382	2,550
N_0	3,217	2,704	2,089	1,474	2,311	2,394
N_1	3,095	2,503	1,958	1,441	2,355	2,504
Cu_0	2,906	2,304	1,869	1,307	2,060	2,266
Cu_1	3,406	2,903	2,178	1,608	2,606	2,632
Mo_0	3,211	2,717	2,111	1,555	2,386	2,482
Mo_1	3.101	2,490	1,936	1,360	2,280	2,416
Mg_0	3.036	2,499	1,892	1,483	2,349	2,332
Mg_1	3.276	2,708	2,155	1.432	2,317	2,566
Sh_0	2.971	2,533	1,959	1,480	2.295	2,470
Sh_1	3,341	2,674	2,088	1,435	2.371	2,428
$Lime_0$	3,739	3,016	2,225	1,523	2,656	2.792
$Lime_1$	2,573	2,191	1,822	1,392	2,010	2,106
TOTALS	6.312	5,207	4,047	2,915	4.666	4,898

and carry a good crop of nuts. Several, however, show slight to moderate yellowing of the foliage and rather poor crop. The number of missing palms is not so great as in the yellow-brown soil area, and so it was possible to lay down this trial in a fairly compact block.

Yield of palms at the commencement of the experiment was estimated at 12 to 13 cwt./acre/annum, with a copra out-turn of about 5,800 nuts/ton. It is, therefore, a better than average block of palms on Papua and New Guinea standards.

The first nut counts were made in November, 1955, and fertilizer was applied in May, 1956. In this case, therefore, the first two sets of records are measures of pre-treatment yield. Details of nut counts to date of writing are shown in Table II. No significant response has been shown to any fertilizer treatment.

Discussion.

The results of these trials up to date have been somewhat disappointing. They have confirmed that there is potassium deficiency in the poorer soils, and indicate that other nutrients probably are fairly adequately supplied. However, the application of potassium fertilizer at a moderate rate did not give a very great increase in yield. Although the appearance of treated palms was improved, they were not brought to what could be called a healthy condition. It is quite possible, considering the very slow cycle of growth of the coconut palm, that the full effect of the fertilizer has not yet become apparent. However, this is not supported by the yield records, as shown in Table II. The graph shows a slight response to potassium evident 12 months after the first application of fertilizer, and this response reached a peak after 18 months, being maintained for a further six months. However, by 30 months after the initial dressing, this response had declined to half, and apparently the second dressing, made six months earlier, had not yet taken effect.

There are two possible conclusions :—

(i) There may be some other factor, in addition to nutrient deficiency, affecting the palms on the poorer soils.

TABLE II.

Nut Numbers: Fertilizer Trial on Red-Brown Clay-Loam Soil.

—	Combined November 1955 and May 1956	November 1956	May 1957	November 1957	May 1958
K_0	9,521	3,902	3,770	4,417	3,383
K_1	9,287	4,109	3,830	4,780	3,360
P_0	9,275	3,894	3,888	4,728	3,298
P_1	9,533	4,117	3,712	4,469	3,445
N_0	9,781	3,900	3,789	4,552	3,324
N_1	9,027	4,111	3,811	4,645	3,419
Cu_0	9,452	3,993	3,711	4,583	3,349
Cu_1	9,356	4,018	3,889	4,614	3,394
Mo_0	10,281	4,169	4,018	4,719	3,503
Mo_1	8,527	3,842	3,582	4,478	3,240
Mg_0	9,450	3,950	3,704	4,417	3,451
Mg_1	9,358	4,061	3,896	4,780	3,292
Sh_0	9,220	3,827	3,684	4,641	3,409
Sh_1	9,588	4,184	3,916	4,556	3,334
$Lime_0$	9,237	3,908	3,770	4,492	3,352
$Lime_1$	9,571	4,103	3,830	4,705	3,391
TOTALS	10,560 | 8,248	8,011	7,600	9,197	6,743

(ii) The rate of application of potassium fertilizer may have been too low or the method of application inefficient, so that the maximum response was not obtained.

Observations over the past three years have not indicated any other factor as likely to be of primary importance. Hence, our current programme is based on the second possibility and two new trials are being commenced, involving different rates and methods of application of potash fertilizer. These will include dressings at the rate of 1 cwt., 2 cwt. and 4 cwt. per acre per annum, comparison of annual and biennial dressings and comparison of close placement (as used in the original trial), with broadcasting over a larger area. In addition, the effect of potash on young seedlings is to be tested in an experiment on underplanting. The main aim of this last experiment (commenced in June, 1958) is to compare the economics of underplanting (i.e., replacement of senile palms by planting new seedlings underneath them, the old palms to be cut out when the new come into bearing) with different levels of thinning of the old stand.

From the practical viewpoint, no firm recommendation can yet be made. The gross return obtained from 2 cwt./acre of muriate of potash has been only about 3 cwt./acre of copra, with indications of little residual effect. This return would not be economic.

The above discussion applies to the heterogeneous palm stands on yellow-brown clay-loam soils. Concerning the red-brown clay-loam soils, it may be stated fairly confidently that, where palms are healthy and bearing well, little or no response could be expected from fertilizing and that it would certainly not be economic.

B. Cultivation Trial.

This is a simple experiment, involving two treatments (ploughing and disc-harrowing) and untreated control.

Since, in these soils, the bulk of the palm's roots are to be found close to the surface, there can be little doubt that over-intensive cultivation, whatever the long term effects, would severely damage the palm initially by cutting a large proportion of its roots. Strip ploughing, therefore, was used, a strip of about 15 feet width being ploughed down alternate rows in alternate years (i.e., treat-

ment to be carried out at yearly intervals). This should effect "root pruning", while treatment of alternate rows only would prevent damage to the palms. The harrowing was repeated at six-monthly intervals and aimed to break up any surface crust on the soil and to turn in the cover crop as a green manure.

The design is a randomized block with four replications. Plots are nominally of 25 trees (5 x 5), separated by a single untreated guard row.

Yield Recording.

The same method of nut counting was used as for the fertilizer trials.

Selection of Site.

The siting of this trial was difficult. On the red-brown clay-loams nearer the shore there is usually so much outcropping coral that cultivation (at least with standard implements) is impossible. On the deeper yellow-brown soils further inland topography is frequently too uneven. A compromise site finally was chosen on an intermediate soil type. The palm stand is fairly old (about 40 years) and shows marked decline, with many palms missing. The number of palms per plot varies from 18 to 23. Yield was estimated at about 4 cwt./acre at the outset, with a copra out-turn of 6,600 nuts/ton.

Experiment and Results.

Although the site had been chosen for its apparent freedom from outcropping rock, the soil proved to be very stony. Wear and tear on machinery, therefore, was very high. The area carried a dense creeping legume cover crop, and it was found impossible to cultivate satisfactorily without first removing this completely. This was especially true in the case of disc harrowing, as even with heavy weights attached the machinery merely rode over the surface and scarcely scratched the soil. For the first cultivation treatments, carried out in March, 1956, the ground, therefore, was thoroughly cleared. However, this adds greatly to the cost of the operation and also is undesirable since it removes organic matter from the soil. For later treatments the cover crop was left as it stood. Ploughing was moderately effective, penetrating three to four inches, and would certainly have effected some root pruning.

Yield records for this trial are shown in Table III. There was no sign of any response at all from either treatment.

TABLE III.

Nut Numbers : Cultivation Trial.

—	Nov. 1955	May 1956	Nov. 1956	May 1957	Nov. 1957	May 1958
Control	2,536	1.872	1.573	1,413	1,585	1,700
Harrow	2,845	2,156	1,847	1.444	1,622	1,739
Plough	2,569	1.888	1.802	1.356	1,573	1.688
TOTALS	7,950	5,916	5.222	4,213	4,780	5,127

Discussion.

The main conclusion from this trial is that cultivation with standard implements is not satisfactory on the bulk of New Ireland soils. Even where cultivation may be practicable, the lack of response in this trial is sufficient to indicate that little benefit could be expected from cultivation of these New Ireland soils.

This experiment has now been abandoned and the site is being used for one of the new fertilizer trials.

Acknowledgement.

The author is indebted to Mr. G. A. McIntyre, of C.S.I.R.O., Canberra, for the design and statistical analysis of all trials described.

THE COCONUT TREEHOPPER, *SEXAVA* SPP., AND ITS PARASITES IN THE MADANG DISTRICT.

By B. A. O'Connor.*

Note by Author.—

THE following article was written in 1941, for publication in the *New Guinea Agricultural Gazette*. The Japanese invasion of New Guinea early in 1942 prevented publication.

Later in 1941, several hundred adult *Sexava* spp, † infested by the Strepsipteron were taken to Manus, where they were liberated on palms at Pak Island, Mokareng plantation, and near Lorengau. Nymphal and adult *Sexava* collected in Manus were then placed in the cages which had been occupied by the parasitized individuals, and a high percentage of parasitism was obtained. The caged *Sexava* were taken to Rabaul and kept under observation. Hosts which had been attacked as adults all died before the next generation of triungulins emerged, death usually occurring about a week after the cephalothorax of the parasite could be seen protruding from the abdomen of the host. Egg production by hosts was definitely inhibited. When the parasite attacked nymphs, its life-history appeared to be longer. From memory, the shortest period from parasitism to emergence of the triungulins was about 50 days. The Japanese invasion prevented the breeding of another generation.

In 1945, the author, who was with the Army in New Guinea, visited and inspected Pak and Mokareng. No sign of the parasite could be found. This was a great disappointment, as there had seemed good reason to expect successful establishment of the parasite, and good control of the host.

Some years later, in a paper by Richard M. Bohart (*A Revision of the Strepsiptera with Special Reference to the Species of North America*, Univ. of Calif. Pubs. in Entomology, Vol. 7, No. 6, pp. 91-160) is was noted that the possibility exists that members of the family Myrmecolacidae, which parasitize ants, may be the males of Stichotrematidae. Bohart quotes Hofeneder as attributing this suggestion to Ogloblin. If this should prove to be the case, a study of the ants of Manam Island, which is very small, might be rewarding. If a myrmecolacid parasite were found in an ant species on Manam which does not occur at Pak, it would appear likely that successful introduction of *Stichotrema* to Manus would call for simultaneous introduction to the ant species also.

THE Madang District of New Guinea has always been free from serious attack by the Coconut Treehopper, *Sexava* spp., while in the Western Islands, Manus, New Britain, New Ireland and Lavongai these insects have frequently caused severe defoliation of coconut palms. Hence, it is obvious that some controlling factor or factors are at work to prevent, except in isolated instances, severe outbreaks of the pest. Therefore, when the writer was instructed to make an entomological patrol of the Madang District, one of the main objects in view was to attempt to obtain information regarding such controlling factors.

During the course of the patrol, which occupied between three and four months, the route followed led around the volcanic islands of Kar Kar and Manam, and along the Madang Coast from Awar Plantation to Madang. Awar is opposite Manam Island,

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† Recently Dr. C. Willemse (Holland) revised the taxonomy of the Mecopodidae and Conocephalidae damaging coconuts in the Territory of Papua and New Guinea. As a result of the revision, one new genus and four new species were described. Their names and distribution are :—

Eumossula gracilis Willemse—New Ireland District (Masahet and Mahurl Islands of the Lihir Group) ; New Britain (Keravat) ; Morobe District (Bubia).

Segestidea hanoverana Willemse—New Ireland District (New Hanover and Tatau Island in Tabar group).

Segestidea insulana Willemse—Manus District (Pak Island, Lou Island, Lorengau) ; New Ireland District (Masahet Island).

(Refer to Willemse, C., 1957. Notes on Medopodidae, Orthoptera, Tettigonoidea. Tijdschrift voor Entomologie, 100, 1 : 35-42.)

Pseudoniscara szentia Willemse—Gulf District.

(Willemse, C., 1958. Natuurhistorisch Maanblad 47, 9-10 : 122-125.)

Species found in the Madang District have not been included in the above-mentioned revision.

and about 140 miles west of Madang by land. Also, a call was made at Muschu Island, about 14 miles west of Wewak, and 200 miles by sea west of Madang. On Manam, which is an active volcano, and where the soil is poor, there are no European plantations, but on Kar Kar, which has very fertile soil of volcanic origin, and on the New Guinea coast, European plantations are scattered along the road. Both Manam and Kar Kar have large native populations, whose groves of coconut palms and bananas provide collecting grounds for *Sexava* spp.

Distribution of Tettigoniids.

A large number of species of *Tettigoniids* was found on coconut palms throughout the district, including what appear to be two distinct species of *Sexava.* The distribution of these two species, the identity of which is not known, is rather interesting. One of them, alluded to as species A, occurs in Kar Kar, Manam and along the mainland coast, and specimens recently have been received from Maprik, an agricultural station south of Wewak, while species B occurs only on the mainland. From Madang to Sarang, which is about 35 miles north and west by sea, only species A was found. From Sarang north-west to Bogia (80 miles by sea from Madang) both A and B were seen, the numbers of A diminishing as one moved westward. West of Bogia, as far away as Awar, only species B was found, and this was also the only species seen at Muschu Island, 200 miles west of Madang by sea. As the patrol did not cover territory east of Madang, no information was obtained as to the species of *Sexava* present in that area. However, specimens from the Huon Gulf, 200 miles by sea south-east of Madang, which are preserved in the insect collections of the Agricultural Department, appear to correspond with species B. Hence, speaking generally, it seems that species B is the typical species of the New Guinea coast, and species A of the islands of Manam and Kar Kar, though the record of species A from Maprik does not fit in.

The most obvious differences in external characters between species A and species B are summarized below in the table.

Species A seems to correspond very closely to an unnamed species of *Sexava* in our collections, a specimen of which was received from Takar, Netherlands East Indies.

Strepsipterous parasites of Sexava spp.

As was mentioned above, one of the main objects of the patrol was to acquire information regarding any factors tending to control *Sexava* spp. The first day in the field revealed the presence of such an influence in the form of an internal parasite of the tree-hopper, belonging to the Order Strepsiptera. This was a most interesting discovery, as it was believed that insects of this Order had not previously been recorded as parasites on species belonging to the Order Orthoptera, to which *Sexava* spp. belong. Neither Imms nor Tillyard, in their standard textbooks, mention Orthoptera as host of Strepsiptera. Moreover, later observations showed that the reproductive rate of the parasite far surpassed that known in other Strepsiptera, a conservative estimate of the number of eggs and larvae in one mature female being 750,000. This figure has no great claims to accuracy, as the difficulty of counting the eggs in their early stages of development is great, but it is thought that the tendency has been rather to underestimate than to overestimate the numbers. Counting was carried out by making a homogeneous mixture of the body

COMPARISON OF SPECIES.

Species A.	*Species B.*
Large. Body-length to tip of elytra: male—approximately 3½ inches. Female—approximately 4 inches.	Small. Body-length of male approximately 2¾ inches. Female approximately 3¼ inches.
Antennae with transverse black bands.	Antennae uniformly brown.
Distal half of elytra wide.	Distal half of elytra narrow.
Thorax without median red stripe, overlapping portion of left elytron unicolorous with rest of body.	Thorax with dorsal median red stripe, overlapping portion of left elytron straw-coloured.
Three or four black spots situated latero-ventrally on the proximal portion of the hind femur. Hind tarsi and distal portions of hind tibiae brownish-black.	No such markings. Ventral portion of hind femur coloured red.

Figure 1
Triungulin Larva of Strepsipteron, Ventral View. (x800)

contents of a mature parasite in glycerine and water, and counting the number of eggs and larvae in a series of single drops of the mixture. The final figure was calculated by multiplying the average number per drop by the total volume of the mixture and dividing by the volume of one drop.

Regarding the identity and host-relations of the parasite, it was later found that a Strepsipteron had been found parasitizing *Sexava nubila*, Stal, and *Sexava* sp. in the Schouten Islands and Admiralty Islands respectively (Pierce, 1918). For this species, named by Hofeneder *Stichotrema dallatorreana*, a new super-family, Stichotrematoidea, was erected. As the species recently found throughout the Madang District has been found in localities adjacent to the Schouten Islands, and runs down to the Stichotrematoidea in Pierce's key to the super-families, it is probably identical with *S.dallatorreana*, Hofeneder. The triungulin larva also corresponds closely to that described by Pierce. The record of the parasite from the Admiralty Islands is regarded as doubtful. Specimens of the insect have been forwarded to the British Museum for identification.

As yet, no detailed study has been made of the biology of the parasite, though it is hoped that some headway may be made in this direction at a later date. However, by piecing together observations made in the field and information gleaned from available literature, it is possible to obtain a reasonable picture of the bionomics of the insect. Among the literature, Kirkpatrick's notable work on the bionomics of *Corioxenos antestiae* has proved particularly helpful.

Bionomics of the Strepsipteron.

The species apparently is parthenogenetic, the female being capable of reproduction without fertilization by a male. Approximately 500 parasitized *Sexava* spp. were dissected during the course of the patrol, and no male puparia were found. The female insect in the adult stage is a crescent-shaped, soft sac, with a strongly-chitinized cephalothorax, and a portion of brown, persistent larval cuticle ventrally. The general body colour is white in the early stages, becoming grey-black as the larvae inside the female body darken. Body-length of a well-developed female is about 4 cm. with a dia-

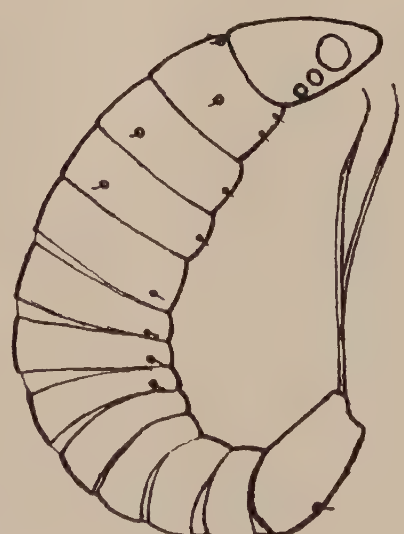

Figure 2
Triungulin Larva of Strepsipteron, Lateral View. Legs omitted (x800)

meter of 1 cm. The parasite spends the bulk of its life inside the body of the host, the only stage which exists in the open air being the minute, heavily-chitinized triungulin larva.

The triungulin larva (Figs. 1 and 2) is dark-brown, heavily chitinized, body-length 0.13 mm., body-width at widest point 0.05 mm. with two strong anally-situated spines, 0.06 mm. long, which enable the larva to spring into the air. On each side of the head there are one large and two small ocelli, ventrally are situated a pair of powerful, sharply-pointed mandibles, while the tarsi of the first pair of legs are provided with large adhesive pads. This type of larva is very hardy, capable of withstanding adverse weather conditions, and surviving for extended periods without food. No first-hand observations of the species have been made, but it is probable that they behave in a manner somewhat similar to the triungulins of *Corioxenos antestiae*, whose behaviour has been fully described by Kirkpatrick. This author states that the larvae attach themselves to any moving object which passes them, deserting it when they find that it is not their host. On finding a suitable host, they remain attached to it until its next ecdysis, when they are capable of penetrating into the body cavity.

Within a short time after entering the body of the host, the triungulin sheds its appendages and heavily-chitinized integument, the second-instar larva being translucent, vermiform and lightly chitinized. Nutriment is absorbed from the blood of the host through the integument, and after several ecdyses the larva pupates, and penetrates one of the abdominal pleura or sterna of the host, portion of the strongly-chitinized cephalothorax protruding slightly from the host's body. The adult insect is partly enclosed in the larval skin, the presence of which on the ventral surface causes a puckering and curving of the abdomen. Two spiracles lead into the main tracheal trunks, which branch internally into a maze of tracheae, supplying the insect with air. A crescent-shaped opening in the cephalothorax gives access to the brood-canal, formed between the larval skin and the ventral surface of the body of the female, and three transverse rows of genital tubes permit the emergence of fully-developed triungulins into the canal, from which they emerge into the open air through the crescent-shaped opening. As the triungulins within the body of the mother approach maturity, they darken, those near the periphery maturing first, and hence becoming visible through the translucent skin of the female, giving the body a grey-black appearance.

Emergence of the larvae has been observed to take place throughout the day, and probably continues at night, as has been described by Kirkpatrick in the case of *Corioxenos antestiae*. The rate of emergence of the larvae is very rapid, a continual stream having been seen to issue from the female for considerable periods. They propel themselves by springing off the anal spines, emerging two or three at a time. During heavy emergence, the brood-canal is filled with a seething mass of triungulins.

Effect of parasitism on the host.

As is the case with other known Strepsiptera, the effect of the parasite is to inhibit, partly or wholly, the production of eggs by the female *Sexava*, and it probably also renders the male infertile, though the testes remain intact. A parasitized female treehopper usually has few or no eggs, and it is not known whether those which remain are fertile. Kirkpatrick has shown, in the case of *Corioxenos antestiae*, that, though the testes of the male host appear normal and produce living spermatozoa, a parasitized male is incapable of fertilizing a female.

Degree of parasitism in Madang District.

The highest degree of parasitism seen during the patrol, based on the percentage of parasitized adults, was on Manam Island, with Kar Kar second and the Madang coast a rather poor third. Not only was the rate of parasitism highest on Manam, but the number of parasites to each host was higher than in other areas. (Dissections were confined mainly to adult *Sexava* spp. and sixth and seventh instar nymphs, though one fifth instar nymph was found to be parasitized. Supplies of the nymphal stages were very small, the natives in the district being unskilled in collecting them, owing to the prevailing ignorance of the treehopper and its life-history.) Stunting of the ovaries and the digestive system of the host was much more obvious on Kar Kar and Manam than on

the mainland, where parasitized females frequently had numbers of well-developed eggs in the ovaries. On the islands, it was rarely that one found even a few eggs in a parasitized treehopper, while the digestive system was often much reduced in size.

The greatest number of parasites found in one host was in a female in Baliau Village, Manam, which contained one mature Strepsipteron attached to the abdominal wall, and 80 larvae in various stages of development. At Dugulaba Village, Manam, one male *Sexava* contained eight mature parasites attached to the abdominal wall, and a female from the same locality had seven. From five to 10 parasites are commonly found in one host at Manam. On Kar Kar, the greatest number of parasites in one host was 16, one mature and the rest in the larval stage. Below is a table showing the percentage of parasitism in Manam, Kar Kar and the Madang coast, based on adult hosts only.

Locality.	Males.		Females.		Total.	
		Per Cent.		Per Cent.		Per Cent.
Manam	74/122	61	92/158	58	166/280	60
Kar Kar	49/123	40	56/110	51	105/233	45
Madang coast	79/368	21.5	122/544	22.4	201/912	22

Projected transfer of parasites to other districts.

As no evidence of hyperparasitism has been found, and as the triungulin larvae of the parasite, which are the only stage existing outside the body of the host, are very hardy, no great difficulty is anticipated in establishing the Strepsipteron in other parts of the Territory. Hence arrangements are being made to collect parasitized treehoppers on Manam Island, where the parasite is most vigorous and successful, and take them to suitable areas elsewhere in the Territory. While attempts are being made to establish the parasite in the field, it is hoped that fuller investigation of its bionomics will be possible. Because Manam is not a port of call for regular shipping lines, and Government transport has been restricted by the exigencies of war, some delay in carrying out this programme is inevitable, but it is hoped that within the next 12 months considerable progress will have been made.

Other species of Tettigoniids attacked by the parasites.

In areas where both are present, the two species of *Sexava*, A and B, seem to be equally susceptible to attack by the Strepsipteron, and, in addition, the parasite has been found in three other species of Tettigoniidae. Two species on Kar Kar were attacked, and one on Manam, but the percentage of infestation was very low, there being only a single record of attack on each species at Kar Kar, while on Manam two adults of a single species were found to be parasitized. The species of parasite in each case is thought to be the same as that which attacks *Sexava* spp., though the size of the adult female is reduced in small hosts.

Tachinid parasite of Sexava spp.

All along the Madang coast, from Awar to Sek, the presence of a Tachinid parasite of *Sexava* spp. was noted, five per cent. of the adults and 10 per cent. of the 6th and 7th instar nymphs being affected. The larvae, in what is presumed to be their first instar, are enclosed in a delicate sac, in which they lie in the abdominal cavity of the host, the head pointing inwards. Anally, the sac is attached to a chitinous funnel, the narrow end of which opens onto the pleural portion of the abdominal wall, thus admitting air to the pair of large spiracles of the larva. The adult fly has not been bred out, and little is known of the life-history of the parasite or its effect on its host, though it is hoped that further knowledge may be obtained at a later date.

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